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# RECOMMENDED PRACTICES FOR THE DESIGN, FABRICATION, PROOFTESTING AND INSPECTION OF WINDOWS IN MAN-RATED HYPERBARIC CHAMBERS

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December 1973

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13. ABSTRACT

A concise recommendation is given for the [illegible]ign, fabrication, proof-testing and inspection in-service of acrylic plastic windows for manned hyperbaric chambers ([illegible] includes PTC's, DDC's, one atmosphere habitats, high altitude simulation chambers, recompression chambers, [illegible]).

The recommendation is limited to a temp[illegible]ature range of -60°F to +150°F and maximum pressure of +3500 psi. The standard window shapes discussed are flat di[illegible] [illegible]ical frustum and spherical shell sector.

Detailed recommendation is also given f[illegible] [illegible]ification and lot acceptance tests that the acrylic plastic material must pass in order to be accepted as fabrication stock [illegible] windows in manned hyperbaric chambers.



58

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| acrylic plastic | | | | | | |
| window | | | | | | |
| view ports | | | | | | |
| decompression chambers | | | | | | |
| personnel transfer capsules | | | | | | |
| undersea habitats | | | | | | |
| vacuum chambers | | | | | | |
| pressure vessel | | | | | | |

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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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## ADMINISTRATIVE STATEMENT

This report summarizes a study performed between January 1972 and June 1973 related to the structural application of acrylic plastic in hyperbaric chambers. The work was supported by the Director of Naval Laboratories through the Independent Exploratory Development Program.


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## SUMMARY

### PROBLEM

Hyperbaric chambers require windows for chamber interior observation during their manned operations. Pressure-resistant windows are not covered by any existing national codes, and the designers, fabricators and operators of hyperbaric chambers frequently must use their own judgment to achieve and maintain a safe window system in a hyperbaric chamber. Inasmuch as most of them are not familiar with the acrylic plastic material used for the windows, they can easily err in specifying windows with an inadequate safety margin.

### RESULTS

Existing data on the design, fabrication and inspection of windows in hyperbaric chambers have been reviewed and checked for applicability to the use of these windows. Based on this study, a set of recommended practices has been proposed and if these practices are followed they will lead to safe window systems in hyperbaric chambers.

### RECOMMENDATIONS

The practices recommended in this report for the design, fabrication and inspection of windows in hyperbaric chambers should receive careful consideration and be used as guidelines when new hyperbaric chambers are being specified or old ones overhauled. Radical deviations from the recommended practices should be used only after a thorough review of all pertinent engineering parameters and experimental validation of the design.

## PREFACE

Most designers, fabricators and operators are unfamiliar with the acrylic plastic material used in the construction of observation windows for hyperbaric chambers. For this reason they could inadvertently specify and procure windows with inadequate safety margins for manned operations.

This report discusses the range of practices recommended for use of the acrylic plastic material in windows of hyperbaric chambers. The information covers material, magnitude of pressure service, type of pressure service and range of ambient temperatures. The plastic discussed is methyl metacrylate, commonly known as acrylic plastic. The pressure service is limited to 3500 psia pressure differential between internal and external pressures, which are understood to be of static or cyclic nature. Temperature service is limited to temperatures in the -60 to +150°F range.

These practices follow the cookbook approach, making their use feasible even by personnel with limited technical background in plastic materials. The recommended practices are not set forth to stifle competent structural engineers in their imaginative research and development designing of window systems for hyperbaric chambers. The recommendations are made, rather, to advise and provide specifications for those engineers who need immediate specifications to procure economical observation chambers with proven state of technological construction. For the engineer experienced in this field, the report provides him with guidelines of what has been done successfully thus far.

## CONTENTS

# SECTION 1

# SERVICE CONDITIONS

Design of windows must be determined by the projected service to which they will be subjected. Only three pressure service conditions are foreseen for the manned chambers in which the windows are located: internal pressurization only, external pressurization only and hybrid pressurization service, in which both internal and external pressurizations are encountered.

In addition to pressure service conditions, there are also temperature service conditions that must be considered. Three temperature service conditions have been established as standard for manned chambers; they are frigid, temperate and tropic. In each case, the type of service is defined by the maximum temperature that ever may be encountered by the hyperbaric chamber *when pressurized*.

## 1.1 PRESSURE SERVICE CONDITIONS

### 1.1.1 Internal Pressurization Service

Internal pressurization service is a loading condition that subjects the chamber solely to internal pressure which is always higher than the external pressure. The internal pressure may be of short duration, long duration, or cyclic. In no case will the interior of the vessel be at a lower pressure than its exterior. The magnitude of the most severe expected pressure loading will be established by computing the maximum absolute difference between the internal and external pressure to which the chamber may be subjected during its projected operational life. This absolute pressure differential will be referred to as the "maximum internal loading."

### 1.1.2 External Pressurization Service

External pressurization is a loading condition that subjects the chamber solely to external pressure that is always higher than the internal pressure. The external pressure may be of short duration, long duration, or cyclic. In no case will the interior of the vessel be at higher pressure than its exterior. The magnitude of the most severe expected pressure loading will be established by computing the maximum absolute difference between the internal and external pressure to which the chamber may be subjected during its projected operational life. This absolute pressure differential will be referred to as the "maximum external loading."

### 1.1.3 Hybrid Pressurization Service

Hybrid pressurization service is a service in which, during the chamber's life, the internal pressure may be higher at times than the external pressure, while at other times the external pressure is higher. To define quantitatively the hybrid pressurization service, it is necessary to know both the maximum internal and maximum external loadings to which the chamber may be subjected during its projected operational life.

## 1.2 TEMPERATURE SERVICE CONDITIONS

### 1.2.1 Frigid Temperature Service

Frigid temperature service is the range of ambient temperatures acting upon one or both faces of the windows where the highest temperature encountered is below +75°F.

### 1.2.2 Temperate Temperature Service

Temperate temperature service is the range of ambient temperature acting upon one or both faces of the windows where the highest temperature encountered is below +120°F.

### 1.2.3 Tropic Temperature Service

Tropic temperature service is the range of ambient temperatures acting upon one or both faces of the windows where the highest temperature encountered is below +150°F.

## SECTION 2

## WINDOW CONFIGURATIONS

Pressure-resistant acrylic plastic windows are available in three standard shapes: circular flat discs, conical frustums and regular spherical sectors (figure 2.1). Depending on the foreseen service conditions to which the chamber will be subjected, the window configuration may employ a single shape or a combination of shapes.

### 2.1 CONFIGURATIONS FOR INTERNAL PRESSURE SERVICE

For internal pressurization only, three standard window configurations are available. Each of these configurations utilizes only a single circular window element (figure 2.2).

#### 2.1.1 Flat Disc Configuration

Uses a single circular flat disc set inside a mounting with a cylindrical cavity (figure 2.2).

#### 2.1.2 Conical Frustum Configuration

Uses a single conical frustum set inside a mounting with a cone shaped cavity whose minor diameter is on the exterior of the chamber (figure 2.2).

#### 2.1.3 Spherical Sector Configuration

Uses a single spherical sector set inside a mounting with a true spherical cone bearing surface whose apex coincides with the center of the sphere (figure 2.2). When set inside the mounting the window has the concave surface on the exterior of the vessel.

### 2.2 CONFIGURATIONS FOR EXTERNAL PRESSURE SERVICE ONLY

For external pressurization, only three standard window configurations are available. Each of these configurations utilizes only a single circular window element (figure 2.3).

#### 2.2.1 Flat Disc Configuration

Uses a single circular flat disc set inside a mounting with a cylindrical cavity (figure 2.3).

#### 2.2.2 Conical Frustum Configuration

Uses a single conical frustum set inside a mounting with a cone-shaped cavity whose minor diameter is on the interior of the vessel (figure 2.3).

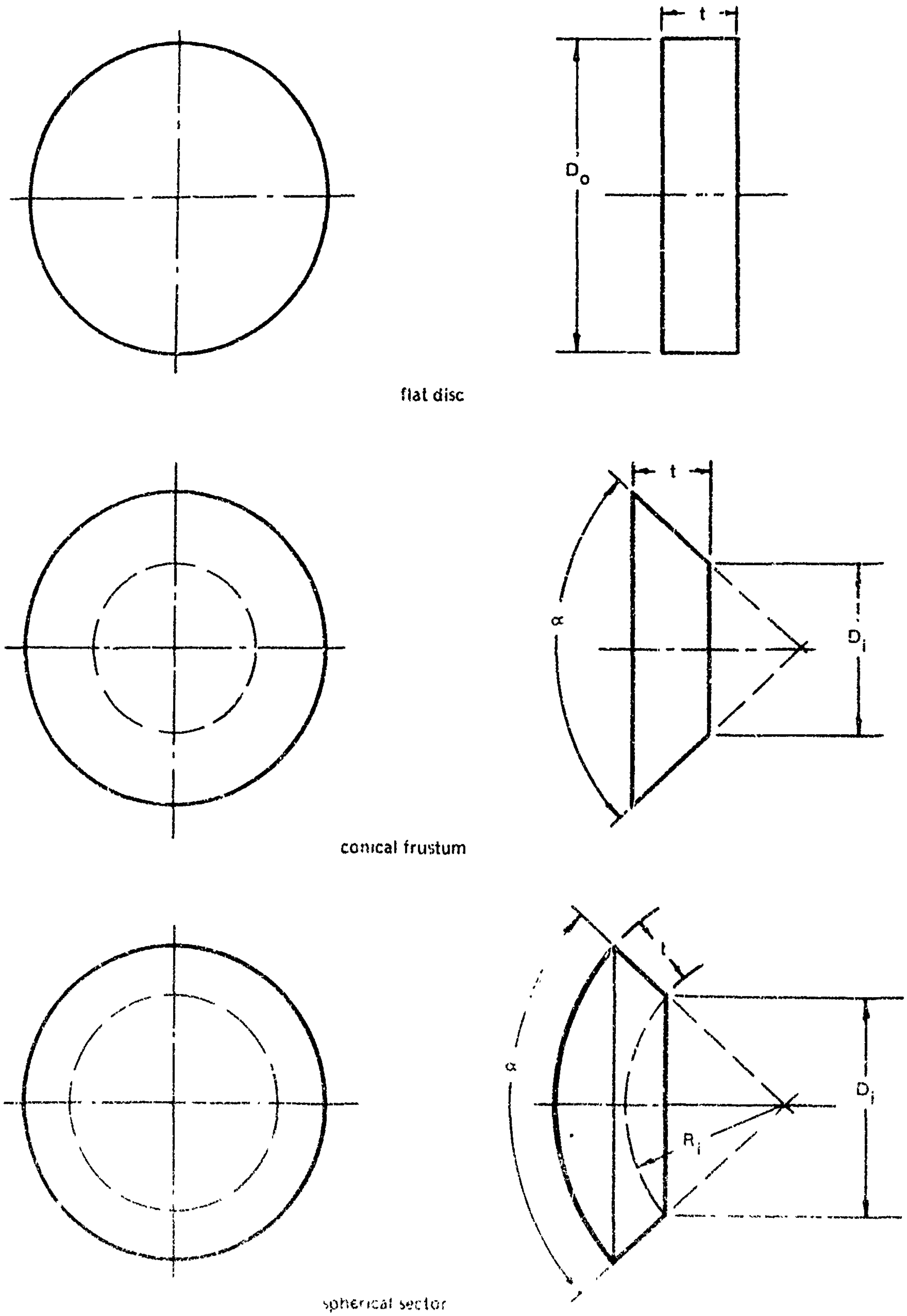
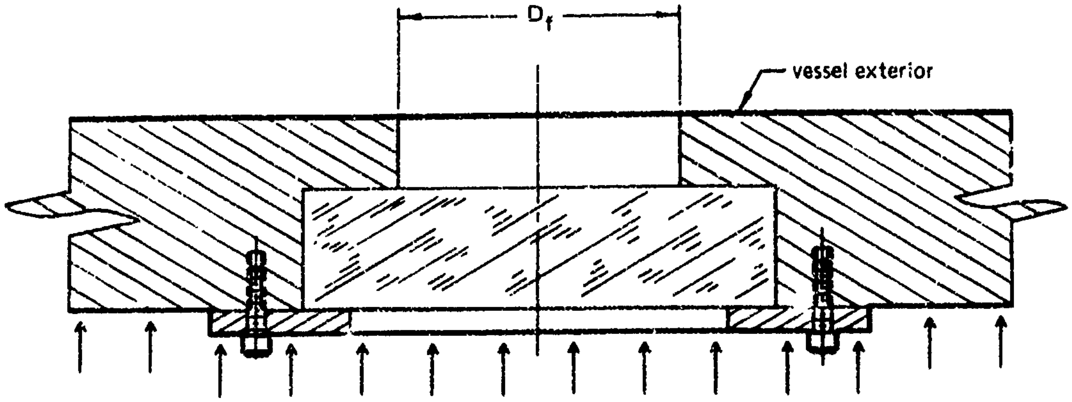
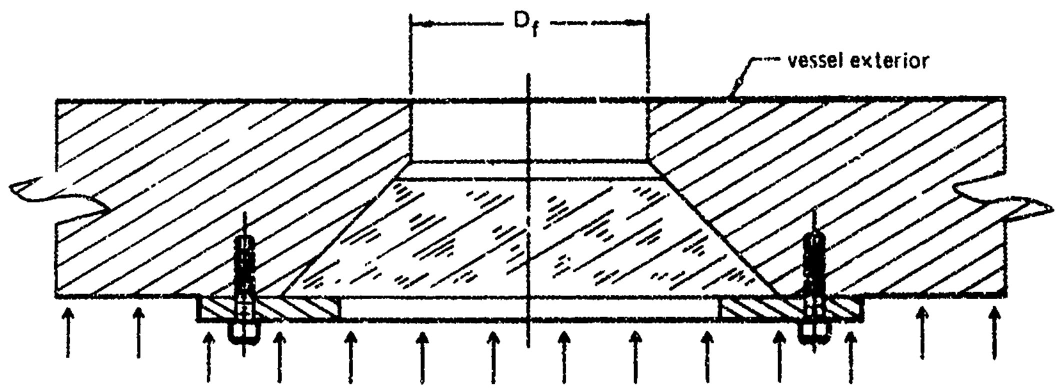


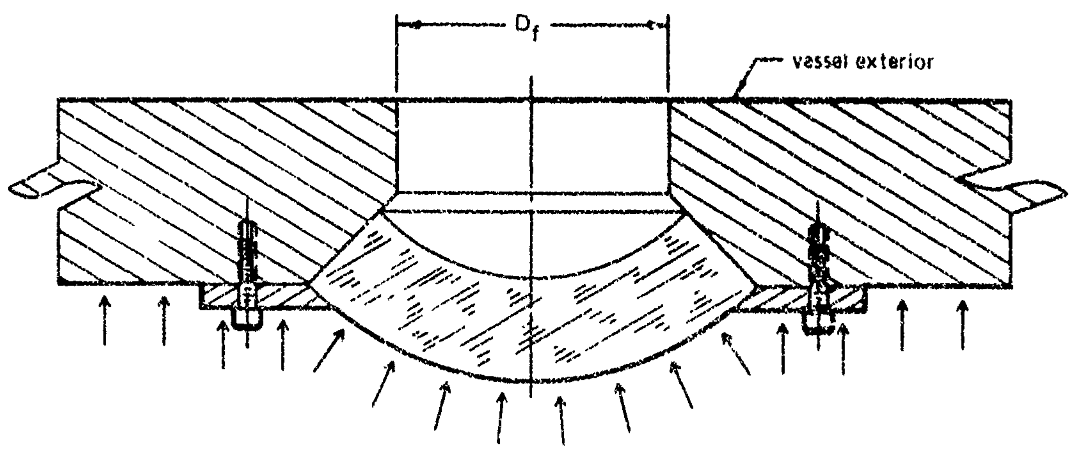

Figure 2.1 Standard window shapes




flat disc window configuration

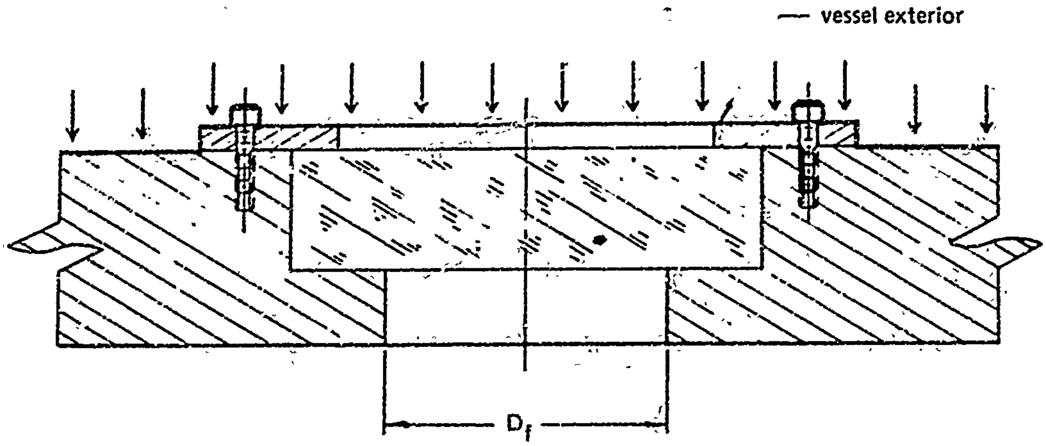



conical frustum configuration

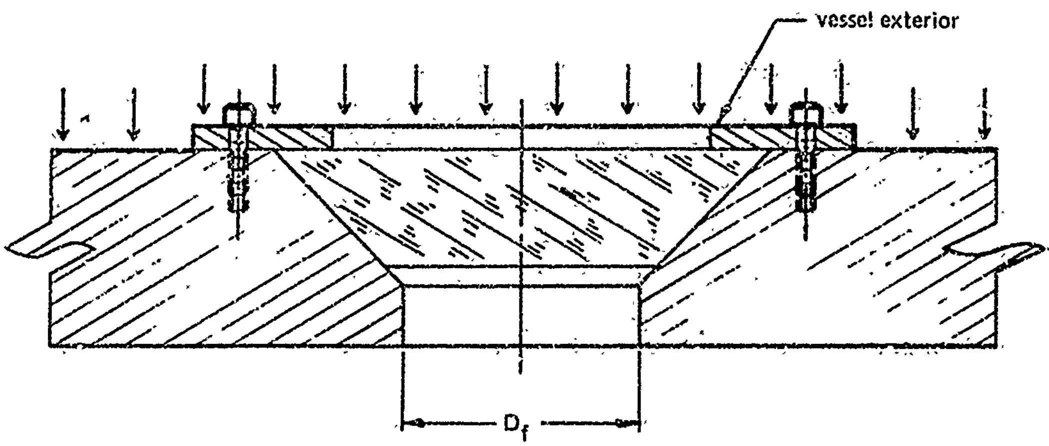



spherical window configuration

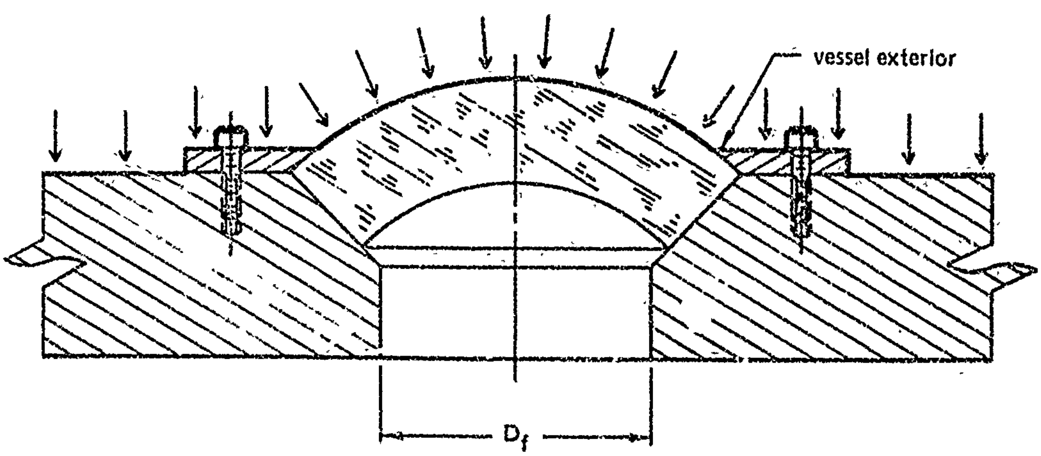
Figure 2.2. Configurations for internal pressure.




flat disc window configuration




conical frustum configuration




spherical window configuration

Figure 2.3. Configurations for external pressure.

### 2.2.3 Spherical Sector Configuration

Uses a single spherical sector set inside a mounting with a true spherical cone bearing surface whose apex coincides with the center of the sphere (figure 2.3). The concave surface of the window is on the interior of the vessel.

## 2.3 CONFIGURATIONS FOR HYBRID PRESSURE SERVICE

There are only three standard window configurations available for hybrid pressure service. Two of the configurations utilize a single window element, while the third uses two (figure 2.4).

### 2.3.1 Flat Disc Configuration

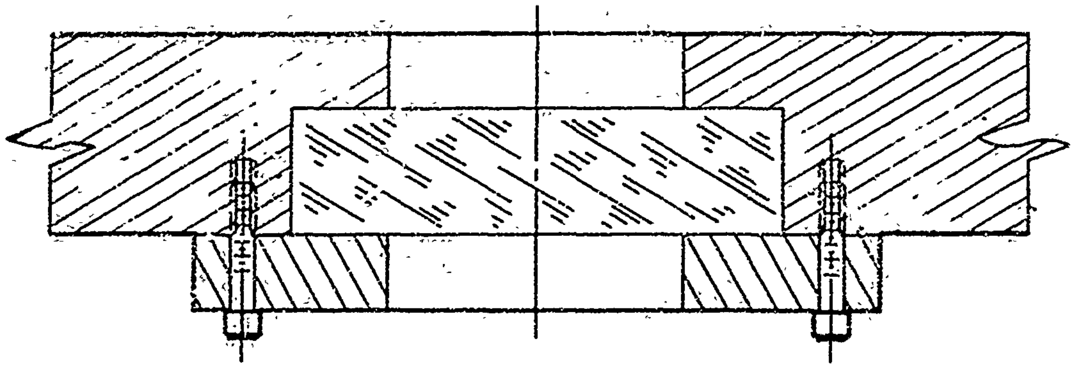
Uses a single circular flat disc set inside a mounting with a cylindrical cavity (figure 2.4).

### 2.3.2 Beveled Disc Configuration

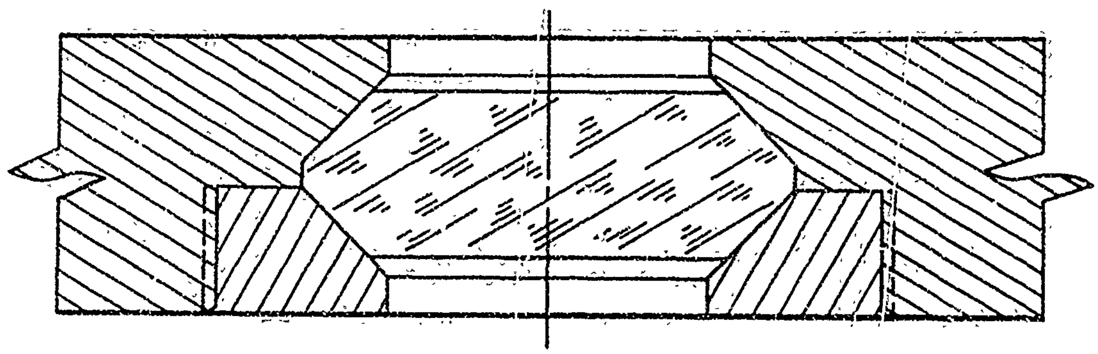
Uses a single circular flat disc with beveled edges set inside a mounting with a matching cavity (figure 2.4).

### 2.3.3 Twin Conical Frustum Configuration

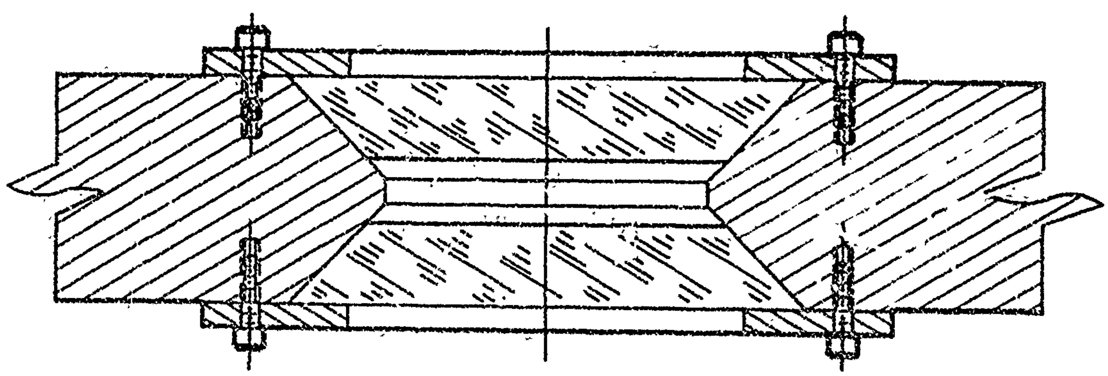
Uses two conical frustums set in a single mounting. The conical frustums are arranged to have their minor diameters facing each other in the mounting.



flat disc window configuration



beveled disc window configuration



double conical frustum configuration

Figure 2.4. Configurations for hybrid pressure loading.

# SECTION 3

## WINDOW DESIGN CONSIDERATIONS

The determination of window dimensions is based on the optical requirements, projected future service conditions and window configuration. Optical requirements are beyond the scope of these design recommendations, they will not be considered here. Window configurations and pressure and temperature service conditions, discussed in Section 2, may be referred to for further information. Service conditions which include not only direction of pressure but also ambient temperatures, also discussed in Section 1, are important and the designer should acquaint himself with the different classifications established for them.

This section addresses itself to the selection of window thickness, dimensional tolerances and surface finishes required to withstand safely the pressure and temperature service conditions encountered during the life of the hyperbaric chamber.

### 3.1 DETERMINATION OF SERVICE CONDITIONS

#### 3.1.1 Type of Pressure Service Condition

The pressure service condition controlling the window design will be determined by establishing whether the hyperbaric chamber under design is subjected to internal, external or hybrid pressurization service.

#### 3.1.2 Magnitude of Pressure Service Condition

The *magnitude* of pressure service condition controlling the window design will be established by determining the maximum internal and/or external pressures the window will encounter during its operational life. Pressures met by windows during proof testing of the whole hyperbaric chamber or individual windows will not be taken into consideration if they do not exceed the maximum operational pressure by 50 percent.

#### 3.1.3 Magnitude of Ambient Temperature

The magnitude of ambient temperature condition controlling the window design will be established by determining the maximum ambient temperature acting upon the window when it is pressurized. Peaks of ambient temperature fluctuations lasting less than 60 seconds and separated by at least a 30 minute interval are disregarded for consideration as maximum temperatures.

### 3.2 METHODS FOR SELECTION OF WINDOW THICKNESS

#### 3.2.1 Nondimensional $t/D_i$ Ratio

The nondimensional overall thickness to minor window diameter ratio ($t/D_i$) is the basic parameter used to establish the required window thickness for a specific set of pressure and ambient temperature service conditions. The validity of $t/D_i$ ratio has been established both analytically and experimentally in scaling window dimensions from model to full scale for hydrostatic pressure service for the three windows recommended for hyperbaric chamber service.

#### 3.2.2 Short Term Critical Pressure

The short-term critical pressure experimentally established on window test specimens at 70°F ambient temperature will serve as the basis for establishing safe operational pressure of windows in hyperbaric chambers. The critical pressure is the hydrostatic pressure on the high-pressure face of the window that will cause a release of pressure and catastrophic structural failure of the window. "Short term" denotes that the pressurization rate is 650 psi/min during destructive testing of windows.

The critical short-term pressures have been experimentally established for the three standard window shapes and their average values have been plotted as a function of window $t/D_i$ ratios (figures 3.1, 3.2 and 3.3). Since a plot of short-term critical pressure for beveled discs (figure 2.4) is not available, the critical pressures of conical frustums (figure 3.2) will be utilized with the provision that the half-thickness of the beveled disc is used for $t$ in the conical frustum $t/D_i$ ratios.

#### 3.2.3 Conversion Factors

Factors designated as conversion factors, correlate the maximum operational pressure with the short-term critical pressure to serve as the basis of window design. The magnitude of a conversion factor expresses the relationship between a window's maximum operational pressure and its short-term critical pressure at 70°F. In practice, the maximum operational pressure is multiplied by the conversion factor to arrive at the required short-term critical pressure for the window.

The magnitudes of allowable conversion factors fall in the range of 4 to 16. The exact magnitude of conversion factor chosen will depend both on the temperature service conditions and on the extent of the additional testing program contemplated for window certification.

Where no additional testing program of windows is contemplated prior to request for certification, the conversion factors will be chosen from the range 6 to 16, the exact magnitude depending upon the temperature service condition. Frigid temperature service condition requires a minimum conversion factor of 6, temperate service condition, a minimum conversion factor of 10 and tropic, a minimum conversion factor of 16. Larger conversion factors

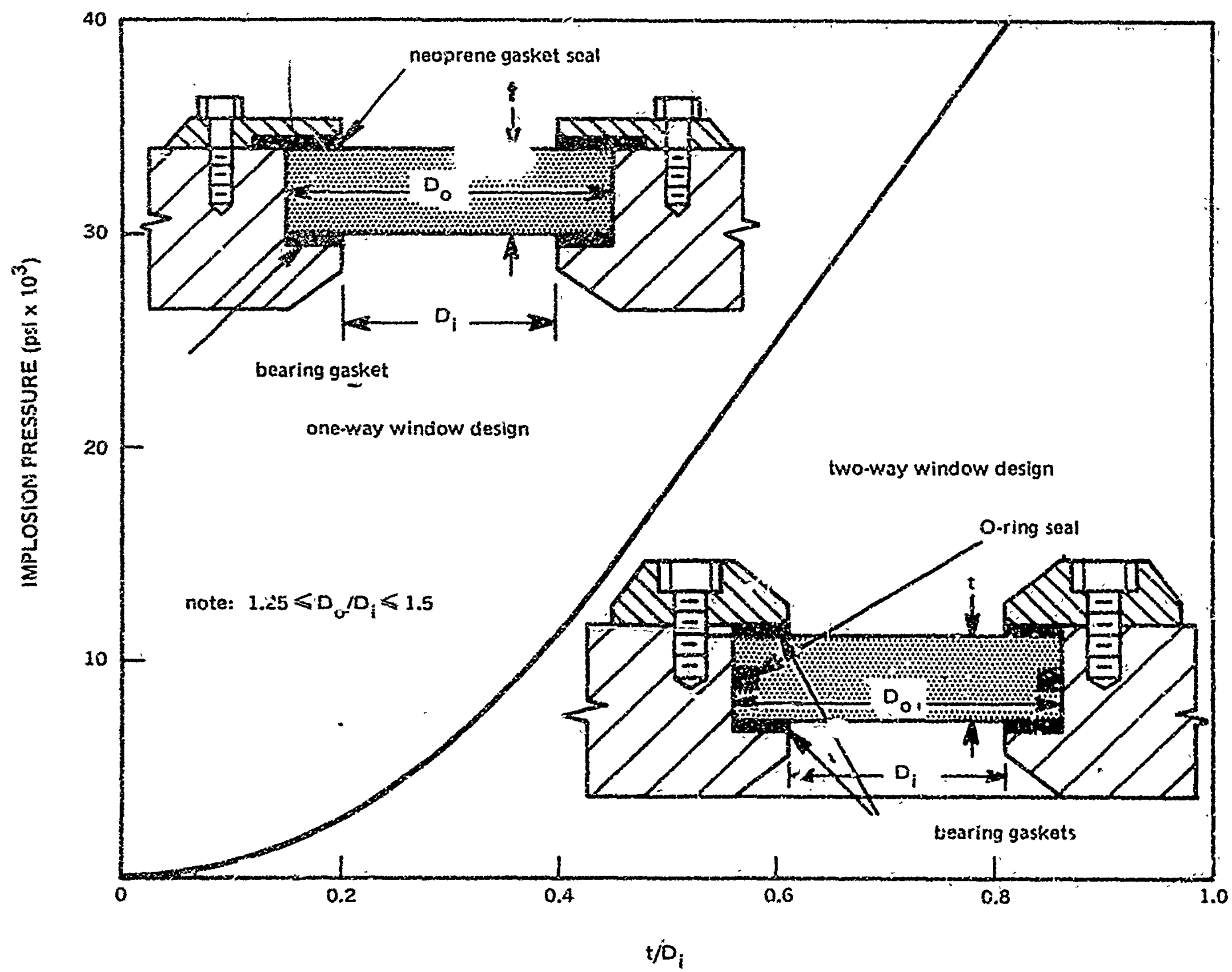



Figure 3.1. Short-term critical pressure of flat disc acrylic windows.

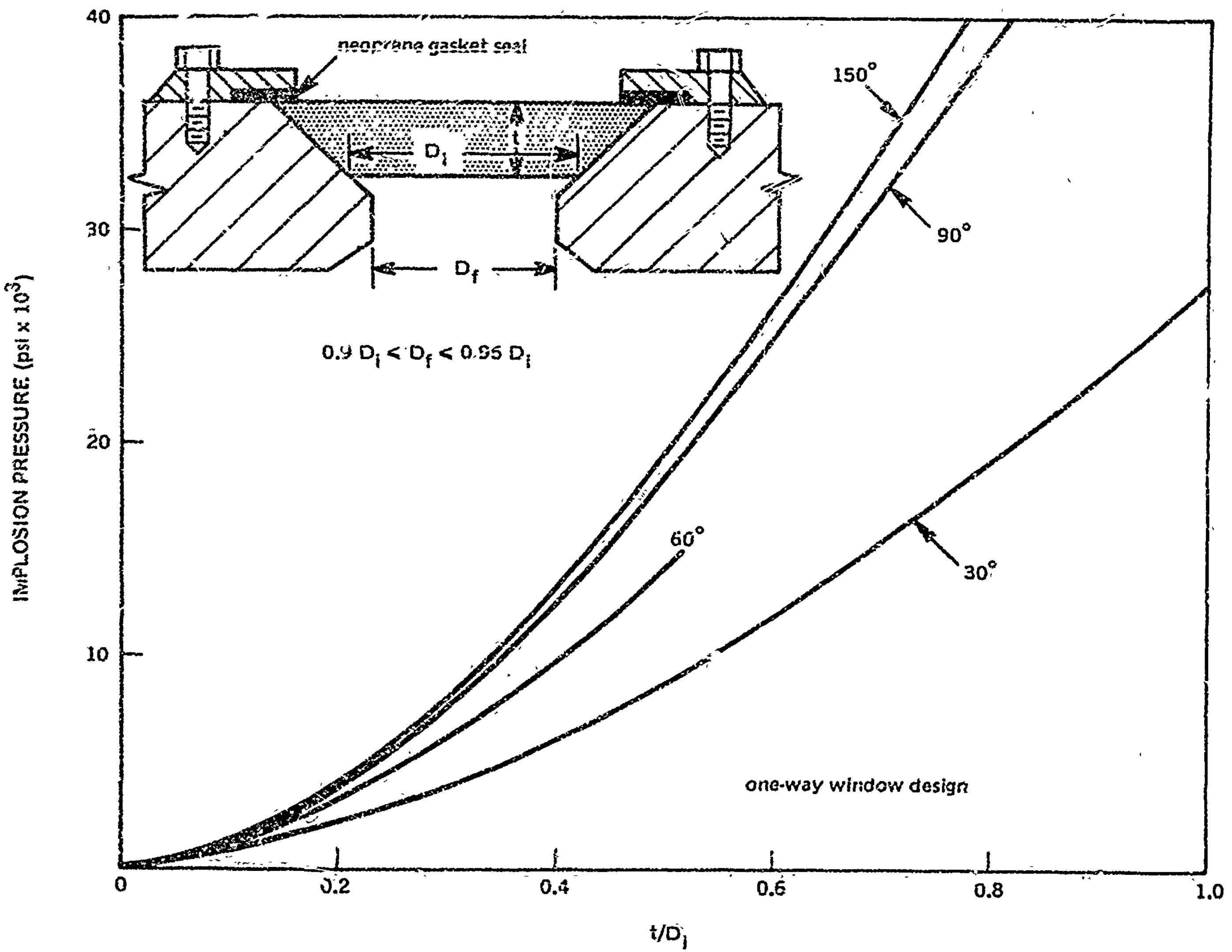



Figure 3.2. Short-term critical pressure of conical frustum acrylic windows.

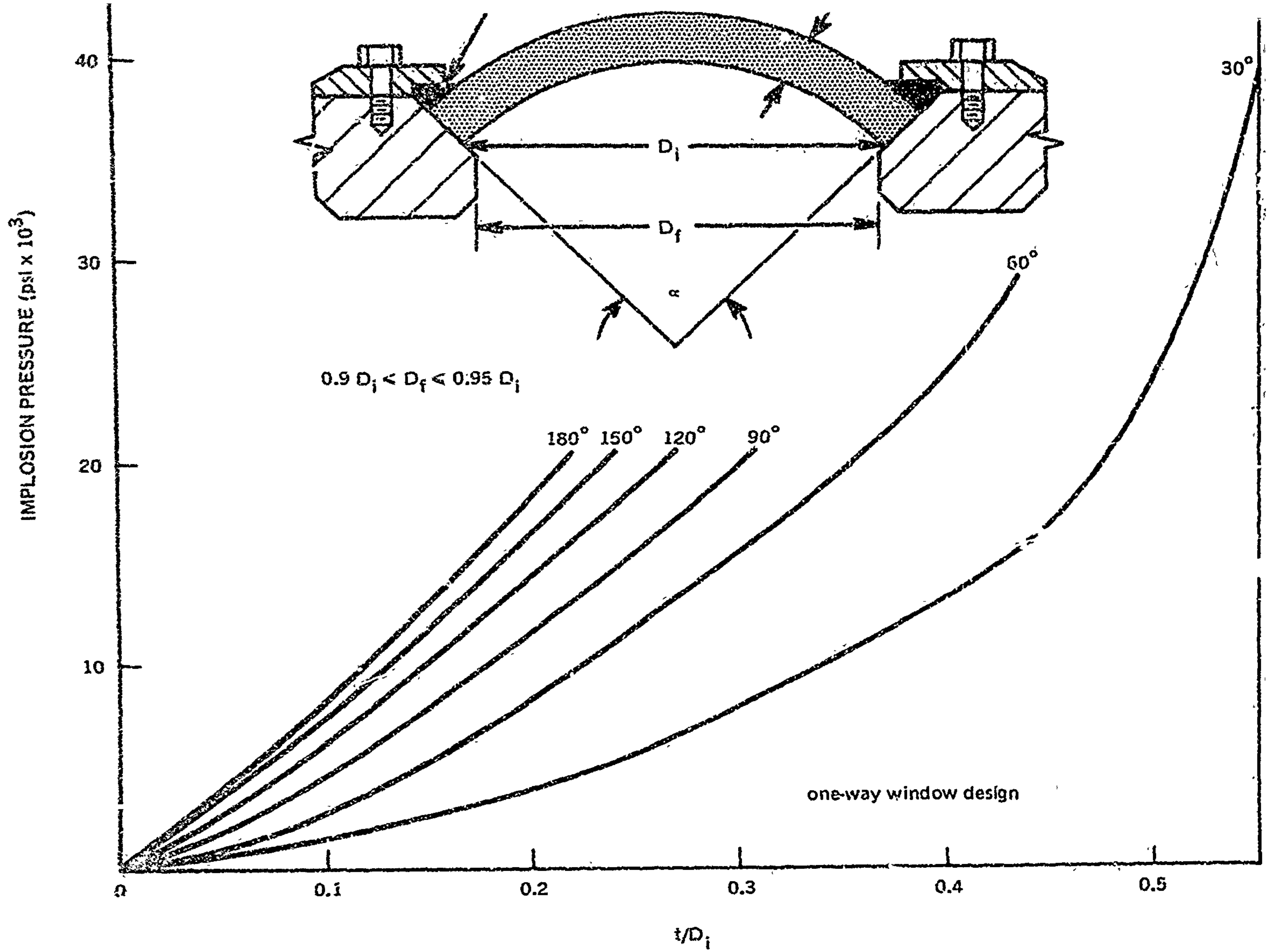



Figure 3.3. Short-term critical pressure of spherical sector acrylic windows.

are permitted but not required, because those specified are adequate for the temperature service conditions shown.

Where additional testing of windows prior to request for certification is contemplated, the magnitude of conversion factors may be decreased to 4, provided the testing follows the requirements discussed next.

### 3.2.4 Validation of Window Design

Where the designer of the windows desires to utilize lower conversion factors than those cited. the burden of proving the window's performance rests upon him. At a minimum, the test program will have to incorporate the following elements:

3.2.4.1 Short-term pressure tests must be conducted on at least five full-scale windows to prove that the average short-term critical pressure of the windows is above a pressure value equal to the maximum operational pressure multiplied by a factor of 4. The tests must be conducted at the highest ambient temperature predicted for the operation of the hyperbaric chamber.

If any of the original five windows fail at a pressure that is 25 percent below the average pressure, an additional five windows must be subjected to short-term tests. If among the additional five windows another specimen fails at a pressure 25 percent below the average value, the average of the two low values will be considered as the accepted average.

3.2.4.2 Long-term pressure tests must be conducted on a minimum of five full-scale windows to prove that the long-term failure of the window under operational pressure and temperature will take place only after a minimum of $10^6$ minutes. In the long-term tests, extrapolated, rather than actual, values may be used to establish the long-term life of the window.

The testing program consists of subjecting individual windows to different sustained pressure loadings and recording the elapsed time to catastrophic failure. If only five windows are used, then the first window should be subjected to 90 percent; the second, to 85 percent; the third, 80 percent; the fourth, 75 percent; and the fifth, 70 percent of average short-term critical pressure established for these windows by prior tests. The tests must be conducted at the maximum ambient temperature predicted for the operation of the hyperbaric chamber.

3.2.4.3 Cyclic pressure tests conducted on a minimum of five full-scale windows must prove that the cyclic fatigue life under operational pressure, temperature and duration of cycle will be in excess of $10^4$ cycles. If the projected average length of an operational pressure cycle is not known, a 24-hour period will be used in its place. In the cyclic pressure tests, extrapolated, rather than actual, values may be used to establish the cyclic fatigue life of the window. The testing program consists of pressure cycling individual windows to different pressure levels until catastrophic fatigue failure occurs. If only five windows are used, then the first window should be cycled to 90 percent; the second, to 85 percent; the third, 80 percent; the fourth, 75 percent; and the fifth, 70 percent of short-term critical pressure established

for these windows by prior tests. The tests must be conducted at the maximum ambient temperature predicted for the operation of the hyperbaric chamber.

3.2.4.4 The extrapolation method allowed for the static long-term and cyclic fatigue tests under operational pressure is based on plotting the experimental data on log-log coordinates and extending the linear graph to infinity. For long-term static tests, the parameters plotted on log-log coordinates are catastrophic failure pressure vs time to failure. For cyclic fatigue tests, catastrophic failure pressure *vs* number of cycles to failure is plotted. In each case, catastrophic failure is defined as leakage of water through the window.

## 3.3 WINDOW DIMENSIONAL TOLERANCES

The proper performance of an acrylic plastic window depends not only on proper design dimensions, but also on machining tolerances.

### 3.3.1 Conical Frustum Window Tolerances

The important dimensions whose deviation from nominal values must be restricted during design are thickness, minor diameter, included conical angle and parallelism of viewing surfaces.

3.3.1.1 The thickness of conical frustum windows must be always equal to or larger than the specified nominal value.

3.3.1.2 The minor diameter of conical frustum windows must be within ±0.002 X $D_i$ inch of the specified nominal value.

3.3.1.3 The included conical angle of conical frustum windows must be within ±15 minutes of the nominal value.

3.3.1.4 Parallelism of the viewing surfaces should be within 0.030 inch. Measurement should be conducted at least at four points around the windows' circumference.

### 3.3.2 Flat Disc Window Tolerances

The important dimensions whose deviation from nominal values must be restricted during design are thickness, outer diameter and parallelism of viewing surfaces.

3.3.2.1 The thickness of flat disc windows must be always equal to or larger than the specified nominal value.

3.3.2.2 The outer diameter of flat disc windows must be within +0.000/-0.010 inch of nominal value (which is the same as the nominal diameter of the cavity in the flange) if a radial O-ring is to be used as the secondary or tertiary seal. If a radial O-ring is not employed for sealing the windows, the diametral tolerance on the nominal value may be as large as +0.000/-0.030 inch.

3.3.2.3 The parallelism of viewing surfaces should be within 0.030 inches. Measurements must be made at least at four points around the windows' circumference.

### 3.3.3 Spherical Shell Sector Windows

For these windows, the important dimensions whose deviation from nominal values must be restricted during design are thickness, sphericity, minor diameter, concentricity and included conical angle. The spherical shell sector acrylic plastic window is more sensitive to dimensional variations than the other window shapes, and because of this, special attention must be paid to its dimensional inspection through use of a set of custom-made measuring tools.

3.3.3.1 The thickness of spherical shell sector acrylic plastic windows must always be equal to or larger than the specified nominal value.

3.3.3.2 Sphericity of spherical shell sector acrylic plastic windows must be within ±0.5 percent of specified nominal external radius of the window.

3.3.3.3 Concentricity of spherical shell sector optical surfaces must be always within ±2 percent of the wall thickness.

3.3.3.4 Minor diameter of spherical shell acrylic plastic window must be within $\pm 0.002 \times D_1$ inches of the specified nominal value.

3.3.3.5 Included conical angle of spherical shell acrylic plastic window must be within ±15 minutes of the specified nominal value.

## 3.4 WINDOW SURFACE FINISHES

The surfaces of acrylic plastic windows must receive proper finish to give the windows the desired optical properties and impart the necessary resistance against initiation of cracks on their bearing surfaces.

### 3.4.1 Conical Frustum Window Finish

In conical frustum windows, the optical finish considerations apply only to the two parallel flat viewing surfaces, while the structural finish considerations apply to the conical bearing surface.

The optical finish on the two surfaces utilized for viewing should meet the requirements of ASTM D702-66 paragraph 6.1.15 (clear print of size 7 lines per column inch and 16 characteristics to the linear inch shall be clearly visible when viewed through the window from a distance of 20 inches).

The structural finish requirement for the conical bearing surface specifies as a minimum a 32-rms machined surface. Finer surface finishes, including polishing, are permissible, but not desirable.

### 3.4.2 Flat-Disc-Window Finish

In flat disc windows, the optical finish considerations apply only to the two parallel flat surfaces. The structural finish consideration applies only to the radial bearing surface around the circumference of the disc.

The optical finish on the two parallel viewing surfaces and the flat bearing areas should meet the requirements of ASTM D 702-66 paragraph 6.1.15.

The structural finish on the radial bearing surface shall be equal to or better than 32 rms.

### 3.4.3 Spherical Shell Sector Window Finish

In spherical shell sector windows, the optical finish considerations apply only to the convex and concave viewing surfaces, while the structural finish requirement applies to the edge bearing surface around the circumference of the window.

The optical finish on the convex and concave viewing surfaces should meet the requirements of ASTM D 702-66, paragraph 6.1.15 when the eye of the observer is located in the interior and at the center of curvature.

## SECTION 4

## WINDOW FLANGES

Flanges for window penetrations have two major functions, they act as structural reinforcement for the window penetration and also serve as a seat for the acrylic window. Because of these dual functions, the flange must satisfy not only the structural requirement of the vessel, but also that of the window.

The selection of flange configuration is based upon the (1) window configuration, (2) the type of pressure service and (3) preferred sealing arrangement. The types of available standard window configurations and the various service conditions have been discussed previously. This section addresses itself to the selection of flange and retainer configuration and sealing arrangements for windows.

### 4.1 STRUCTURAL CONSIDERATIONS

Regardless of the flange configuration and sealing arrangement chosen, there are certain structural parameters that must be considered in the design of the window flange for acrylic plastic windows.

#### 4.1.1 Flange Stresses and Deformations

Because of the large mismatch between the modulus of elasticity in the plastic window and the metallic flange, it is assumed that the window does not provide any reinforcement for the hull material around the penetration. All of the reinforcement for the hull penetration must be provided by the window flange. Any of the accepted analytical or empirical methods for stress calculations may be used for dimensioning the thickness, width and location of the flange around the window penetration, provided that the resultant flange stresses and deformations meet the following minimum requirements:

4.1.1.1 Radial deformation of the window seat at maximum internal or external operational pressure must be less than 0.003 X $D_f$ inches.

4.1.1.2 Angular deformation of the window seat at maximum internal or external operational pressure must be less than 0.5 degree.

4.1.1.3 The peak stress measured on a window penetration flange at maximum operational pressure shall always be less than one half of the flange material's yield strength under uniaxial tensile loading.

#### 4.1.2 Flange and Retainer Subassembly Configuration

The flange and retainer subassembly configuration will be chosen to match the desired window configuration and sealing arrangement. Once a flange and retainer subassembly

configuration has been chosen for a particular type of pressure service, the hyperbaric chamber becomes limited to that particular type of pressure service. Later changes in the flange configuration are costly and time-consuming. For this reason, considerable thought must be exercised prior to choosing the flange configuration.

In the design of the retainer subassembly, one must consider two types of loading conditions. The *primary* loading consideration is the retention of the window in the flange seat under a specified magnitude of hydrostatic loading. The magnitudes of hydrostatic pressure that the windows must withstand are given in paragraphs 4.1.2.1 through 4.1.2.3. The *secondary* loading consideration is the precompression of elastomeric gaskets serving as the primary seal in the window assembly. A good rule of thumb for estimating the magnitude of loading imposed by precompressed elastomeric gaskets and O-rings is to multiply the outer window diameter in inches by 2000 pounds. If the secondary loading is calculated to be larger than the primary, the design of the retainer subassembly configuration will have to be based on the larger loading value.

4.1.2.1 Internal pressure service requires that the window retaining ring subassembly be located on the interior of the vessel. It must be designed structurally to retain the force generated by an external hydrostatic pressure of 15 psi (figure 2.2). The minimum safety factor specified for the retainer subassembly requires that water leakage may occur through the window penetration only at external hydrostatic pressures higher than 60 psi.

4.1.2.2 External pressure service requires that the window retaining subassembly be located on the exterior of the vessel. It must be designed structurally to retain the force generated by an internal hydrostatic pressure of 15 psi (figure 2.3). The minimum safety factor specified for the retainer subassembly requires that water leakage may occur through the window penetration only at internal hydrostatic pressures higher than 60 psi.

4.1.2.3 Hybrid pressure service requires that the window retaining subassembly be located on the side of the vessel exposed to the *higher* operational pressure. It must be designed structurally to retain the force generated by the most severe difference in external and internal pressures acting on the vessel. The minimum safety factor specified for the retainer subassembly requires that water leakage may occur through the window penetration only at a pressure differential 4 times higher than predicted for the operation of the vessel (figure 2.4).

## 4.2 WINDOW SEAT REQUIREMENTS

Acrylic plastic windows must be supported properly in order to optimize their structural strength. Proper support for the window requires that the seat in the window flange match closely the window bearing surface, allow for movement of the window under load and have a finish adequate for pressure sealing and reducing friction caused by movement between the flange and the window.

### 4.2.1 Window Dimensional Tolerances

Since the primary function of the window seat is to give the window adequate support when it is subjected to hydrostatic loading, a close match must be insured between the window seat and the window body. The close match can be attained by close dimensional control of the window and of the window seat.

4.2.1.1 The conical cavity seat must have an included conical angle that is within ±5 minutes of the nominal value. The minor diameter ($D_f$) of the window seat must be within $\pm 0.002 \times D_f$ inches of the nominal window penetration diameter.

4.2.1.2 Cylindrical cavity seats must have an outside diameter within +0.001/−0.000 inches of nominal value if the radial O-ring is to be used as the secondary seal. If elastomeric gaskets are used as both primary and secondary seals, the tolerance on the outside diameter may be as large as +0.020/−0.000 inches. The diametral tolerance on the inside seat diameter is ±0.020 inch regardless of what kind of secondary seal is used on the window.

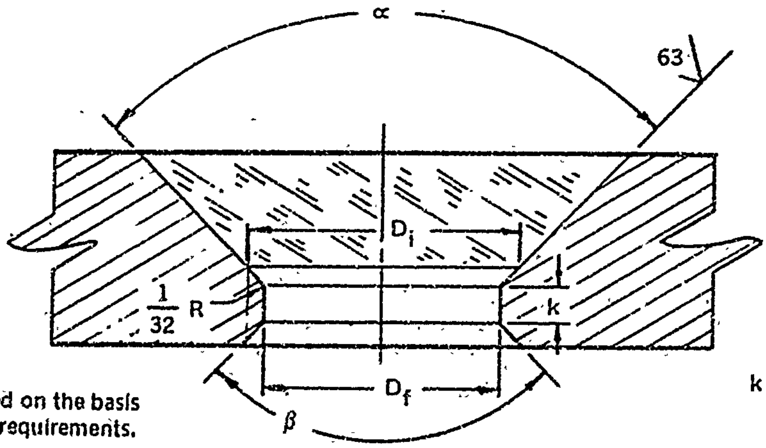
### 4.2.2 Seat Dimensions

The seat dimensions must be adequate to give the window not only sufficient bearing area when it is under zero pressure loading, but also when it is stressed and displacing under proof-test pressure equal to 1.5 times operational pressure.

4.2.2.1 The conical cavity seat has two major requirements. The depth of the conical window cavity must be sufficient to give the window (figure 4.1) support throughout its full length and the minor window seat diameter, $D_f$, must be smaller than the minor window diameter, $D_i$. The difference between these diameters assures adequate radial and axial support to the window, which is creeping under hydrostatic loading. The magnitude of the difference is a function of operational pressure, temperature, length of sustained hydrostatic loading and magnitude of conversion factor used in the window design. Since it would be too cumbersome to establish a set of individual guidelines that would cover each possible case, a general rule has been established. This general rule gives $D_i/D_f$ values that are very adequate for most, and very conservative for some, operational window requirements. Shown in figure 4.1 are the minimum $D_i/D_f$ values considered necessary for adequate support of windows using conical seats.

4.2.2.2 Cylindrical cavity seats have three major requirements. The seat will be located in a cylindrical cavity whose depth is equal to or in excess of the window thickness The maximum nominal diametral clearance between the window and the cavity wall will be 0.005 $D_O$ inch if no radial O-ring seals are used, and 0.01 in. when they are not used. The ratio between the seat cavity diameter, $D_O$, and the minor penetration diameter, $D_f$, must be in the 1.250–1.500 range to give the window adequate bearing support during hydrostatic loading (figure 4.2).

note : the $D_i/D_f$ ratios shown are valid only for operational pressures $\leqslant$ 3500 psi.



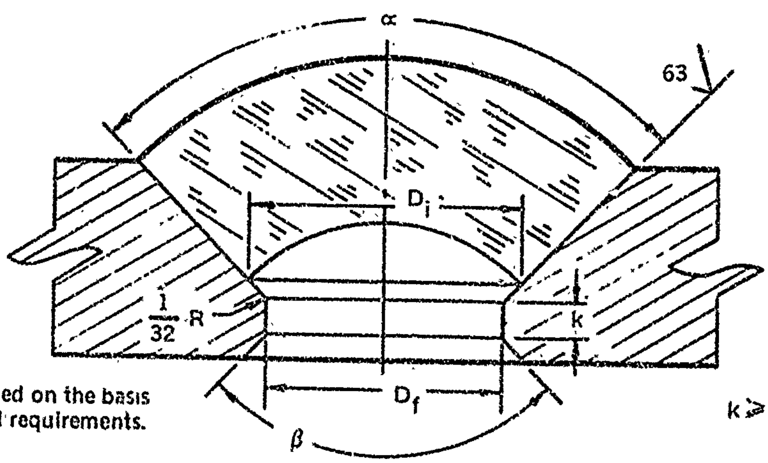

$\beta$ is selected on the basis of optical requirements.

$k \geqslant 0.1\ D_i$

| | | | | | | |
|---|---|---|---|---|---|---|
| ∇∇ | included angle ($\alpha$) | 30° | 60° | 90° | 120° | 150° |
| ∇ | $D_i/D_f$ ratio | 1.03 | 1.04 | 1.06 | 1.12 | 1.28 |

a. conical frustum window

note : for $\alpha$ between values shown interpolation is required.




$\beta$ is selected on the basis of optical requirements.

$k \geqslant 0.01\ D_i$

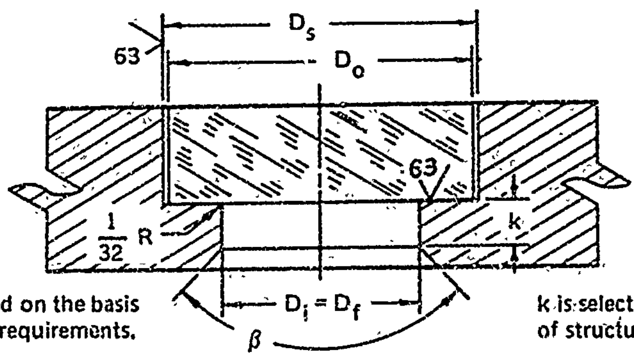
| | | | |
|---|---|---|---|
| ∇∇ | included angle ($\alpha$) | 30° thru 90° | 120° thru 180° |
| ∇ | $D_i/D_f$ ratio | 1.05 | 1.10 |

b. spherical shell sector window

Figure 4.1. Conical seat cavity requirements.

$0.000 \leq D_s - D_o \leq 0.005\ D_o$

depending on seal used




$\beta$ is selected on the basis of optical requirements.

k is selected on the basis of structural analysis.

$1.250 \leq D_o/D_f \leq 1.50$

Figure 4.2. Cylindrical cavity seat requirements.

### 4.2.3 Seat Finish

Proper finish is necessary on the surfaces of the seat to provide a good seal surface and a smooth sliding surface for the extruding window. Without adequate surface finish, the seal may be inoperative and cracks may be generated in the window bearing surfaces prematurely.

4.2.3.1 Conical cavity seats must have a finish that is equal to or better than 63 rms.

4.2.3.2 Cylindrical cavity seats must have a finish on all the internal surfaces that is 65 rms or better.

## 4.3 SEALING CONSIDERATIONS

Elastomeric seals must be incorporated into the window flange assembly to act as a primary barrier against leakage of gases and water through the window penetration. Since the choice of a particular seal arrangement will require the use of a window retainer subassembly especially suited for that seal arrangement, the designer is advised to choose them at the same time.

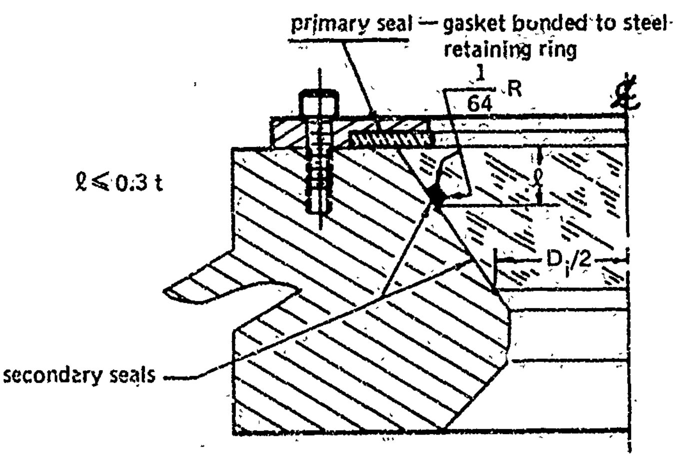
In addition to a primary seal, there also must be a secondary seal, which may be of the elastomeric or grease type. Grease seals may act as secondary seals wherever permitted by the window configuration. The window configurations that allow the use of grease seals as a secondary seal are those that have a conical bearing surface mating intimately with a conical window seat. In the case of flat disc windows, the secondary seal must also be of the

elastomeric type. In other window configurations it is at the option of the designer to choose between the elastomeric and grease type sealing arrangements for the secondary seal.

### 4.3.1 Conical Frustum Window Seals

The conical bearing surfaces must be equipped with both a primary and a secondary seal. The primary seal must, in addition, act as a bearing gasket for the window retainer ring.

4.3.1.1 The primary seal must be a flat elastomeric gasket (neoprene or similar) bonded to the window retainer ring or an O-ring wedged into a properly dimensioned groove (figure 4.3). The thickness of the gasket will be adequate to allow the necessary precompression specified for installation. In no case will the precompression exceed 50 percent of the original gasket thickness. The precompression specified for the primary seal depends on the conical angle; its value is given in figure 4.3. The hardness of the elastomeric gasket must not exceed 90 Durometer.




use 60 durometer or softer elastomers

| primary seal precompression during assembly | | | | | |
|---|---|---|---|---|---|
| included angle (α) | 30° | 60° | 90° | 120° | 150° |
| precompression (operational pressure > 1500 psi) | $\geq 0.06\ D_i$ | $\geq 0.04\ D_i$ | $\geq 0.03\ D_i$ | $\geq 0.03\ D_i$ | $\geq 0.03\ D_i$ |
| precompression (operational pressure < 1500 psi) | $\geq 0.03\ D_i$ | $\geq 0.02\ D_i$ | $\geq 0.015\ D_i$ | $\geq 0.015\ D_i$ | $\geq 0.015\ D_i$ |

Figure 4.3. Sealing of conical frustum windows.

4.3.1.2 The secondary seal may either be grease between the mating conical surfaces or an elastomeric O-ring located in a groove that has been machined into the conical bearing surface of the window (figure 4.3). O-ring seals are not recommended if the $t/D_i$ ratio of the window is less than 0.25. O-ring should be of $\leq 60$ Durometer hardness.

### 4.3.2 Flat Disc Window Seals

Flat disc windows with flat bearing surfaces must be equipped both with a primary and a secondary seal. Because of the uniqueness of the cylindrical disc shape, a tertiary seal may be incorporated also.

4.3.2.1 The primary seal must be a flat elastomeric gasket bonded to the retainer ring. The hardness of the gasket must not exceed 90 Durometer unless the window is used in hybrid pressure service, in which case the hardness should be at least 90 Durometer, since the gasket serves then also as a window bearing gasket (figure 4.4).

4.3.2.2 The secondary seal must be a flat elastomeric gasket bonded to the bearing surface on the seat (figure 4.4). Since the secondary seal gasket serves also as a bearing gasket, its hardness should be at least 90 Durometer to keep it from extruding when under load.

4.3.2.3 The tertiary seal (optional) shall be radially compressed O-ring located in a groove machined around the circumference of the window (figure 4.4). If desired, the tertiary seal configuration may be substituted for the secondary seal configuration. The O-ring should be of 90 Durometer hardness.

### 4.3.3 Spherical Shell Sector Window Seals

Spherical shell sector windows must be equipped with primary and secondary seals (figure 4.5). Since the spherical shell sector windows have low $t/D_i$ ratios as a rule, it is difficult to incorporate O-rings into the conical window bearing surface.

4.3.3.1 The primary seal must be an elastomeric gasket wedged between the external window surface and the flange. The hardness of the O-ring should not exceed 60 Durometer.

4.3.3.2 The secondary seal must be grease trapped between the mating conical surfaces of the window and the flange.

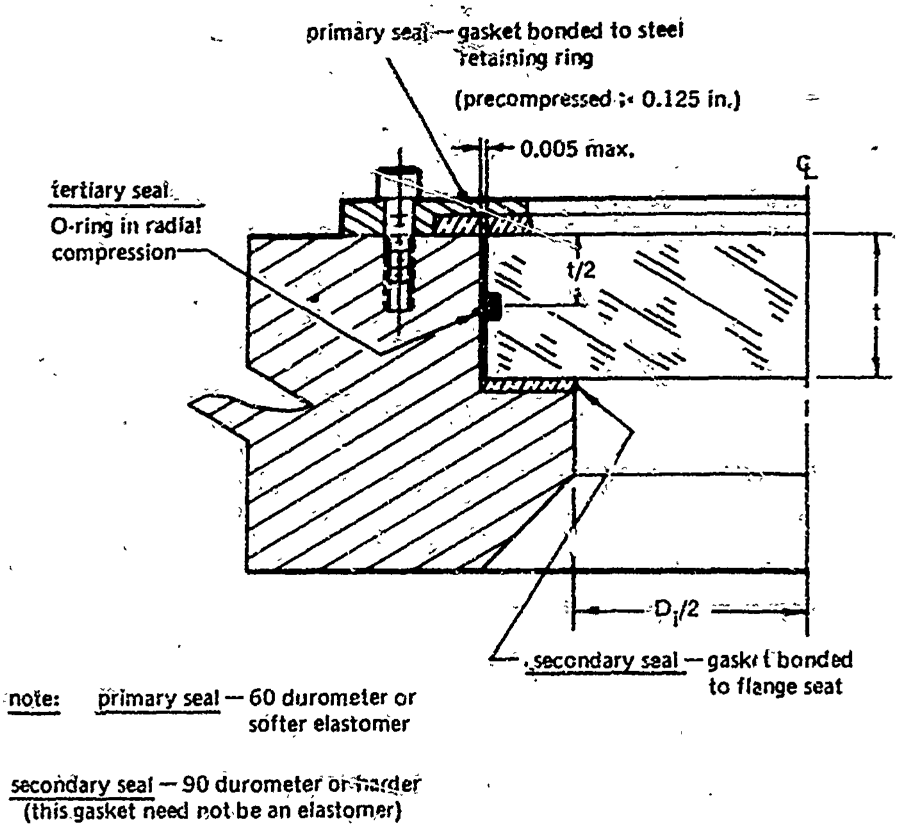
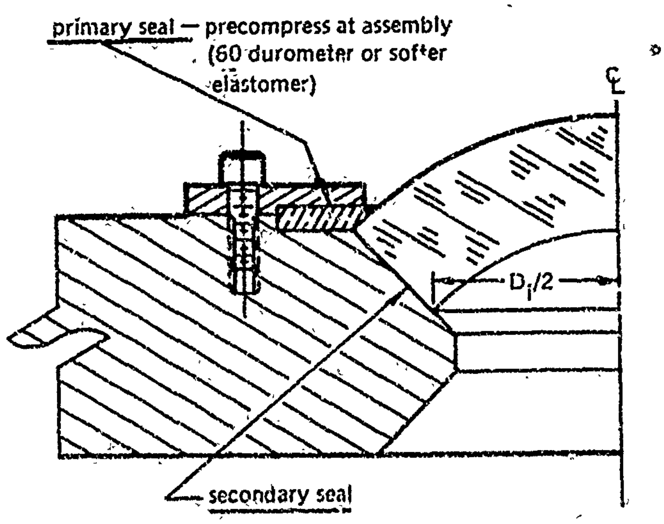



Figure 4.4. Sealing of flat disc windows.




| operational pressure | < 1000 psi | < 2000 psi | < 3000 psi |
|---|---|---|---|
| seal precompression | ≥ 0.01 $D_i$ | ≥ 0.02 $D_i$ | ≥ 0.03 $D_i$ |

Figure 4.5. Sealing of spherical shell sector windows.

# SECTION 5

# FABRICATION

It is necessary that certain basic steps be followed during the fabrication of windows and flanges to insure that the finished product has the structural properties designed into it. Since the procedures for fabricating acrylic plastic windows differ significantly from those which apply to the metallic hull with flanges, they will be discussed separately. The fabrication procedures for flanges are somewhat similar to those for the hull and will be discussed in the section on chamber hull fabrication.

## 5.1 TRACEABILITY

### 5.1.1 Material Accounting and Identification System

A material accounting and identification system must be used during fabrication of windows. Identification numbers will be applied to and maintained on each piece of material so it will be possible at any time to trace any piece of raw material, window blank or finished window to the original casting or sheet from which it was cut.

### 5.1.2 Identification of Finished Windows

Identification of finished windows must be accomplished by using red or black felt tip markers that have no deleterious effect on plastic. Identification of each window will consist of the manufacturer's name, date of fabrication and a number assigned to it by the fabricator to permit tracing it to the stock of material from which it originated. The identification will be placed on the conical bearing surface for conical frustums and spherical sectors and on the cylindrical surface of flat disc windows.

## 5.2 THERMAL SHRINKING OF STOCK

Windows for service at 150°F must be thermally shrunk prior to machining them to final dimensions. The thermal shrinkage will be accomplished by subjecting the windows to a minimum forming temperature of 325°F for at least four hours. At that time, a lateral shrinkage of approximately two percent and a thickness increase of four percent should occur. The cooling rate from the forming temperature to room temperature should not exceed 15°F/hour.

## 5.3 MACHINING

### 5.3.1 Dimensions of Windows

Dimensions of windows will be based on 70°F temperature and 50 percent humidity as produced by soaking in a 70°F air atmosphere with 50 percent humidity for 24 hours.

Because the material expands from frictional heating and contracts under flow of coolant over the machined surface, the contractor will find it necessary to determine experimentally the appropriate dimensions to be used by the machinist during machining.

### 5.3.2 Lubricants and Coolants

Lubricants and coolants used during the machining operations of acrylic plastic must be water soluble and approved by their manufacturer for such application.

## 5.4 FORMING

The temperatures used during forming operation must not be less than 300°F or more than 360°F. Forming operation will be employed only for spherical shell sector windows.

## 5.5 ANNEALING

Annealing of windows must take place at least once and preferably twice. If it is annealed only once, the operation should take place after all the machining and polishing of the windows has been completed. If the annealing operation is performed twice, the first time should be after rough machining, and the second, after final machining. The annealing cycle will consist of a warm-up period (at a maximum 15°F/hour rate) to 175°F, a heat-soaking period of 24 hours duration and a cooling-down period to room temperature (at a maximum 10°F/hour rate).

## 5.6 PROOF-TESTING

### 5.6.1 Proof-Testing of Windows

Each window must be proof-tested at least once prior to being approved for service in man-rated hyperbaric chambers. As a minimum, it will be subjected to the overpressure proof-test when the complete hyperbaric chamber is proof-tested prior to its acceptance for man-rated service. It is best to proof-test the window when it is mounted in the hyperbaric chamber since the window is supported during the test by the flanges in which it will see service during its operational life.

A window may be also proof-tested twice before being placed into man-rated service; the first time by the window fabricator in a simulated flange and a second time by the chamber operator when the windows are mounted in the chamber and he proof-tests the whole system. The first proof-test can be conducted in a flange that is not stressed in a manner identical to that of the flange in the hyperbaric chamber. The only requirement for the simulated window flange is that it have the same window seat and retainer dimensions as the operational flange in the chamber.

### 5.6.2 Magnitude of Pressure

The magnitude of pressure used in the proof-test must be no less than the operational pressure for which the chamber will be rated and no more than 1.5 times the operational pressure. The pressure will be applied at a rate that is not in excess of 1000 psi/minute.

If the window assembly undergoing the tests is designed for hybrid service then one proof-test must be applied to satisfy the internal pressure requirement and another to satisfy the external pressure requirements.

### 5.6.3 Ambient Temperature

Ambient temperature during the proof-test should not exceed the maximum expected operational temperature for the chamber at any time. If the chamber window design is rated for frigid temperature service, the maximum temperature allowed during the proof-test is 75°F. If the chamber window design is rated for temperate temperature service, the maximum allowable temperature during the proof-test is 120°F. If the chamber window design is rated for tropic temperature service, the maximum allowable temperature during the proof-test is 150°F.

### 5.6.4 Instrumentation

Instrumentation will be employed during the proof-test only on a single specimen of a given class (design) of windows. The instrumentation will consist either of a simple electrical-resistance strain gage bonded to the center of the window's low-pressure surface or a mechanical dial indicator resting against the center of the window's low-pressure face. The dial indicator must read in 0.001-inch increments.

If the window assembly is intended for hybrid pressure service, the strain gage and dial indicator should be applied consecutively for the internal and external pressure requirements.

### 5.6.5 Data Recording

Displacement or strain of the window will be recorded at 100-psi intervals during the pressurization and at one hour intervals during relaxation at 0 pressure after the test. The displacements and strains should return to within 0.010 inch and 50 microinches/inch of original values, respectively.

### 5.6.6 Duration of Proof-Test

Duration of the proof-test must not exceed the maximum length of a typical projected chamber pressurization. In the absence of any other specific recommendation, a four hour pressure hold and four hour relaxation period will be considered standard for proof-test purposes.

### 5.6.7 Arrangements

Arrangements for the proof-test should never combine the maximum allowable proof-test pressure and temperature simultaneously. If this is done, serious damage may occur in the window during proof-test. It is recommended instead that if 50 percent overpressure is applied to the window, the temperature be kept in the 70-90°F range. On the other hand, if the proof-test entails *no overpressure*, the maximum allowable temperature can be utilized.

### 5.6.8 Recommended Procedure

To assure that the proof-testing achieves its objective without shortening the fatigue life of the window, it is recommended that the proof-test be performed in two steps:

1. Proof-test the window prior to installation in the hyperbaric chamber by pressurizing it to maximum operational pressure *only* at maximum temperature allowed for that service. The pressure should be sustained for 4 hours.
2. Proof-test the window to 50 percent overpressure when the entire chamber assembly is proof-tested. The temperature during that test should not exceed 75°F nor last longer than 4 hours.

## SECTION 6

## ACCEPTANCE OF HARDWARE

It has been assumed that the fabricators of windows and window flanges will strive to comply with the previously recommended practices to produce a reliable viewport for man-r[illegible]d operation. Still, a written record certifying their compliance with those recommendations helps to crystallize their actions and focus the quality control process on the area vital to safe structural performance.

### 6.1 WINDOWS

The written records required for certification of windows must show that the design, material, fabrication process and proof-testing complied with the guidelines called out in the preceding recommendations.

#### 6.1.2 Design Record

The design record composed of a fabrication drawing and engineering calculations must show that the following parameters were considered and their magnitude or character established:

a. Type of pressure service and the magnitude of maximum operational pressure that the chamber will see (e.g., 300 psi maximum, internal pressure only).

b. Type of temperature service and the numerical limits of the temperature range (e.g., -20°F to 95°F, temperate zone service).

c. Window shape chosen (e.g., 90° conical frustum shape).

d. Conversion factor used to arrive at the required window thickness (e.g., conversion factor of 10).

e. Short-term critical pressure calculated on the basis of conversion factor and maximum operational pressure (e.g., 10 X 300 = 3000 psi short-term critical pressure).

f. Thickness-to-diameter ratio ($t/D_i$) calculated on the basis of operational pressure, conversion factor and empirical design curves (e.g., $t/D_i = 0.20$ for CF = 10, MOP = 300 psi when figure 3.2 is used).

g. Dimensional tolerances recommended for the window shape chosen have been entered on the fabrication drawing (e.g., dimensional tolerance on thickness, diameter, and included angle).

h. Surface finishes recommended for the window shape chosen have been entered on the fabrication drawing.

### 6.1.3 Material Qualification Record

The material serving as basic stock for fabrication of windows must comply with the provisions of the specifications recommended for acrylic plastic windows in hyperbaric chambers (see Appendix A). The proof of compliance consists of Material Data Forms 1 and 2, which substantiate the claim that the material is on the Qualified Product List and, subsequently, on the Lot Acceptance List.

6.1.3.1 **Qualified product listing** for the material must be justified either by the material supplier (he submits a filled-out and notarized Material Data Form 1) or by the window fabricator, who has all the qualification tests done by an independent testing laboratory (the laboratory conducting the tests submits a notarized Material Data Form 1). Not every acrylic casting has to be tested for QPL. The fabricator can qualify a particular acrylic casting product with a single series of tests.

### 6.1.4 Fabrication Record

The fabrication record, composed of material accounting form, identification tracer, fabrication process rider and quality control certificate, must show that the following items were recorded:

a. Material stock used in the fabrication of a window must be positively identified on the material accounting form.

b. Lot and item numbers on the identification tracer accompanying a window must correspond to the markings on the window.

c. The fabrication process rider accompanying a window must show entries describing the following:

1. Thermal regimen used in shrinking of material
2. Thermal regimen used in forming of window
3. Coolants used during machining
4. Thermal regimen used in annealing of window lot

d. The quality control certificate accompanying each window must show that the window has been inspected and the following items noted.

1. Minor diameter
2. Major diameter
3. Conical angle (if any)
4. Thickness (at three different locations)
5. Sphericity (at three locations)
6. Optical finish on viewing surfaces
7. Structural finish on bearing surface

8. Presence of inclusions in the material
9. Presence of chips and scratches

### 6.1.5 Proof-Testing Record

The proof-testing record, composed of the test description and window performance data, must show that the following items were recorded.

a. Temperature of water (or gaseous atmosphere) in contact with the window during the test.

b. Pressurization rate used to reach proof-test pressure.

c. Proof-test pressure to which the window was subjected.

d. Duration of constant proof-pressure loading on the window.

e. Depressurization rate used to depressurize the window.

f. Displacement or strain of the window center during the proof-test and subsequent relaxation period (performed only a typical window chosen from the window lot).

g. Visual inspection of the window after the proof-test.

## SECTION 7

## INSPECTION AND MAINTENANCE OF WINDOWS IN SERVICE

On exposure to harmful cleaners or high temperatures acrylic plastic may deteriorate in service to such an extent that it may lose its optical value and structural strength. Rough handling and repeated overpressurizations may also induce surface cracks and scratches that subsequently initiate fractures which lead to catastrophic failure of the window. For this reason, it is necessary to subject installed windows to periodical visual inspections and maintenance.

### 7.1 INSPECTIONS

All windows installed in man-rated pressure-resistant vessels must be visually inspected periodically for signs of optical and structural deterioration. Both operational and maintenance inspections must be made.

#### 7.1.1 Operational Inspection

The operational inspection must be conducted by the operator just prior to each pressurization of the hyperbaric chamber. The inspection will be visual and no additional instruments beyond a flashlight are required for its conduct. During this inspection the condition of visually accessible exterior, interior and bearing surfaces will be observed and noted in the hyperbaric chamber logbook. Presence of blemishes in the form of crazing, cracks, scratches, blisters and discolorations require careful evaluation of their effect on the structural integrity of the window and its ability to serve safely under maximum operational pressure.

7.1.1.1 Blemishes on the low-pressure face are a grave source of concern since they can initiate catastrophic failure in flat disc and conical frustum windows. On flat disc and conical frustum windows with $t/D_i < 0.5$, the presence of a crack or scratch deeper than 0.010 inch, crazing, blisters or discoloration will necessitate immediately removing the window and replacing it with another unit. Crazing, blisters, discoloration and cracks or scratches in windows with $t/D_i \geqslant 0.5$ will necessitate immediate window removal if the blemishes penetrate more than $0.01t$ below the low-pressure face. A window having blemishes less than $0.01t$ but more than 0.010 inch will be permitted to serve until next scheduled maintenance inspection, at which time it must be replaced with another unit. Blemishes less than 0.010 inch deep can be tolerated indefinitely.

Blemishes on the low-pressure face of a spherical sector window deeper than $0.02t$ will necessitate the immediate removal of the window and replacement with another unit. A window with blemishes less than $0.02t$ but more than 0.010 inch will be permitted to serve until next scheduled maintenance inspection, at which time it must be replaced. Blemishes less than 0.010 inch deep can be tolerated indefinitely.

7.1.1.2 Blemishes on the high-pressure face as a rule, are not very serious unless they are very deep. Only those blemishes deeper than $0.02t$ will necessitate the immediate replacement of the window. Windows with blemishes less than $0.02t$ but more than 0.020 inch will be permitted to serve until next scheduled maintenance inspection, at which time they must be replaced. Blemishes less than 0.020 inch deep can be tolerated indefinitely.

7.1.1.3 Blemishes on the conical bearing surfaces deeper than 0.060 inch will necessitate the immediate removal and replacement of the window. Windows with blemishes less than 0.060 inch but more than 0.010 inch deep will be permitted to serve until next scheduled maintenance inspection, at which time they must be replaced. Blemishes less than 0.010 inch can be tolerated indefinitely. The same considerations also apply to blemishes in the surface around the circumference of flat disc windows.

7.1.1.4 Chipped edges of windows necessitate the immediate removal of the window only if the chipped high-pressure face edge precludes sealing of the window or the chip missing from the low-pressure face edge is longer than $0.1D_i$ or deeper than $0.02D_i$ inch.

### 7.1.2 Maintenance Inspection

Maintenance inspection must be conducted at least once every calendar year, and at that time the windows must receive a more thorough inspection than during the operational inspections. During this inspection, *all* surfaces of the windows must be visually inspected. If this cannot be accomplished without removal of retaining rings, then they must be removed.

At the time of the maintenance inspection, it is necessary to remove all the windows on whose surfaces blemishes have been discovered either during the previous operational inspections or the maintenance inspection. All of the windows removed from the hyperbaric chamber can be subsequently placed back in service if the blemishes causing their removal are eliminated by polishing, sanding, machining or patching.

## 7.2 MAINTENANCE OF WINDOWS

The primary parameter that must be considered prior to repairing a window is its actual thickness. If after repair, the thickness of the window is more than $0.01t$ below the thickness required by Section 3.2, the window will be considered unsuited for the pressure service in which it was previously used. For this reason it is considered prudent to specify as original equipment windows that are 5 to 10 percent thicker than specified by Section 3.2. In this manner some material stock is always available for sanding and machining during window maintenance operations of blemished high- and low-pressure faces.

### 7.2.1 Annealing

After sanding, machining or recasting of window surfaces, it is recommended that the window be annealed to increase its potential resistance to cracking. The annealing should take

place at 175°F for 24 hours, followed by a cooling-down period in which the temperature is reduced at a maximum of 10°F/hour to room temperature.

### 7.2.2 Casting and Cementing

If deep blemishes are repaired by patching with a polymerizing acrylic cement, test data must be provided (by the cement supplier) to show the compressive and tensile strength of the cements is not less than 50 percent of the parent material strength. Building up a window's thickness by casting in place is permitted, provided the resulting increase in thickness is less than $0.1t$ and the strength of the casting and its adherence to the window material is not less than 50 percent of the parent material strength.

# APPENDIX A
# PROPOSED SPECIFICATION FOR ACRYLIC PLASTIC MATERIAL

## SECTION 1
## SCOPE AND TYPE OF MATERIAL

### 1.1 SCOPE

1.1.1 This specification covers clear transparent methyl methacrylate castings of nominal 1/2 inch or greater thickness. These sheets or finished shapes are intended to be used as pressure-resistant, structural-component viewing apparatus in manned chambers under internal pressure, external pressure, or both, e.g., submersibles, decompression chambers, transfer capsules, etc. Superior physical and mechanical prop.rties are required in addition to optical properties.

1.1.2 This specification does not cover the finished product, i.e., the window itself.

### 1.2 TYPES OF MATERIAL

This specification covers three types of cast methyl methacrylate plastics.

1.2.1 Type 1 – Unshrunk, ultraviolet-light-absorbing and heat-resistant material having greater shrinkage than Types 2 or 3 when heated to thermoforming temperatures.

1.2.2 Type 2 – Pre-shrunk, ultraviolet-light-absorbing and heat-resistant material.

1.2.3 Type 3 – Pre-shrunk, ultraviolet-light-absorbing, heat-resistant and craze-resistant material.

## SECTION 2

## APPLICABLE PUBLICATIONS

Current (as of the date of this specification) issues of the following documents are part of this specification to the extent noted herein.

### 2.1 TEST METHODS

2.1.1 ASTM. The following American Society of Testing Materials (ASTM) test methods shall be used where specified.

| Test No. | ASTM Designation | Title or Subject |
|---|---|---|
| 1 | D 256-70 | Impact properties of rigid plastics |
| 2 | D 542-50 | Refractive index of plastics |
| 3 | D 570-63 | Water absorption in 24 hours of plastics |
| 4 | D 621-64 | Deformation of plastics under load |
| 5 | D 637-50 | Surface irregularities of flat transparent plastic sheets |
| 6 | D 638-68 | Tensile properties of rigid plastics |
| 7 | D 648-56 | Deflection temperature of plastics under flexural load |
| 8 | D 695-69 | Compressive properties of rigid plastics |
| 18 | D 696-70 | Coefficient of linear thermal expansion of plastics |
| 17 | D 702-68 | 6.1.15 clarity, visual rated |
| 9 | D 732-46 | Shear strength of rigid plastics |
| 10 | D 785-65 | Rockwell hardness of plastics and electrical insulating materials |
| 11 | D 790-70 | Flexural properties of rigid plastics |
| 12 | D 792-66 | Specific gravity of plastics |
| 13 | D1003-61 | Light transmission of plastics |
| 15 | E 308-66 | Practice for spectrometry and description of color in CIE 1931 sy m |

Copies of these are available from ASTM, 1966 Race Street, Philadelphia, Pa. 19103.

### 2.1.2 Military Specifications

| Test No. | ASTM Designation | Title or Subject |
|---|---|---|
| 19 | P-8184B | 4.5.5 Craze Resistance |

Copies available from Naval Supply Depot, 5801 Tabor Avenue, Philadelphia, Pa. 19120.

### 2.1.3 Other Publications

| Test No. | ASTM Designation | Title or Subject |
|---|---|---|
| 14 | SPE Transactions | Residual Monomer "Gas Chromatography, a New Test for Analysis of Plastics" by Cobbs Samsel, April 1962, p. 150-151. |

## SECTION 3

## MATERIAL

### 3.1 GENERAL

The material shall be cast in the form of blocks for individual windows or sheet stock from which several windows may be machined. These should be of sufficient oversize to permit cutting of lot acceptance test specimens prior to machining, thermoforming, etc., of the window(s) from the casting. Qualification test specimens and supplementary lot acceptance test specimens can be taken from material normally shipped to the procurer.

### 3.2 RAW MATERIALS

The manufacturer is given a wide range in the selection of raw material and in the process of manufacture, provided the material furnished is a transparent plastic conforming to all requirements of this specification and is suitable for the intended use. The supplier is responsible for notifying the procurer of any major formulation changes that might affect qualification test results to the extent that the material would no longer pass these tests. Upon notification the material so designated must be resubmitted for QPL testing.

### 3.3 LOT DEFINITION

The material shall be supplied in a fully polymerized state (see Table 2, Test 14) and shall be a monolithic homogeneous solid. A lot is that material produced in one pour from the same monomeric material and made at the same time, undergoing identical processing from monomer to polymer. This includes different thicknesses *if* the preceding two statements hold.

## SECTION 4

## CLASSIFICATION OF TESTS

### 4.1 QUALIFICATION TESTS FOR QPL LISTING

Acrylic sheet furnished under this specification should be a product which has been tested and passed the qualification tests specified herein. Qualification tests shall be made on one casting of the first lot (see 3.3 and 4.2) of material furnished under this specification and any subsequent lot of material designated by the specifying agency or the procurer (see 4.6.2). Passing of the qualification test is the basis for listing on the Qualified Products List (QPL). A notarized copy of the test results (see Form 1) should always accompany the shipment of castings from any grade of material. Some qualification tests are lot acceptance tests. Provided qualification test results are available, those tests which are in common need not be rerun for lot acceptance or vice versa.

### 4.2 THICKNESS CLASSIFICATION

QPL listing of material of one thickness within the thickness ranges shown in Table 1 qualifies other thicknesses within the same range. That is, the QPL lists particular material (tradename and grade), and thickness categorics' combinations. Each different material/thickness combination must be tested and submitted separately for listing on the QPL. Thickness of 1/2, 1, 2 and 4 inches are preferred, but not required, for qualification testing.

### 4.3 LOT ACCEPTANCE TESTS

Only materials listed on or approved to be listed on the QPL are acceptable under this specification. In addition, each casting is to be tested and pass the Lot Acceptance tests specified herein. A single casting cut or split into several pieces need only pass the Lot Acceptance tests once. A notarized copy of the test results (see Form 2) shall accompany each casting shipped to the fabricator.

Table 1. Thickness Categories Based on Nominal Thickness Ranges.

| Nominal Thickness Range | Thickness Category |
|---|---|
| Equal to 0.500 in. | 1. |
| Greater than 0.500 to 1.000 in. | 2. |
| Greater than 1.000 to 2.250 in. | 3. |
| Greater than 2.250 to 4.250 in. | 4. |
| Greater than 4.250 in. | 5. |

## 4.4 VISUAL INSPECTION

Each sheet or casting conforming to this specification must be inspected separately and meet the requirements of visual inspection specified herein.

## 4.5 TESTING RESPONSIBILITY

4.5.1 Qualification Tests. The material supplier may qualify his product by submitting data (Form 1) for QPL. For nonqualified material the procurer is responsible for doing or having done the qualification tests.

4.5.2 Lot Acceptance and Visual Inspection Tests. Lot Acceptance tests and visual inspection tests are the responsibility of the material supplier. The procurer can buy QPL listed material off-the-shelf and do or have done the lot acceptance and visual inspection tests.

## 4.6 RETEST

4.6.1 Rejected Material. Unless there is legitimate reason to doubt the reported values, rejected material shall not be resubmitted.

4.6.2 Periodic Qualification Checks. The procurer may ask that qualification tests be done on any lot of ordered material. Values reported on these rechecks shall take precedence over original qualification test results and passing them shall be the basis for QPL listing. These are the responsibility of the procurer. Those tests done for lot acceptance need not be rerun for qualification recheck.

# SECTION 5

# REQUIREMENTS

## 5.1 QUALIFICATION TESTING

**5.1.1 Tests and Values Required.** Tables 2 and 3 list the tests that must be made and the required values of qualification tests for conformance to the specification.

Table 2. Qualification Tests that Apply to all Thicknesses.

| Test No. | Property | Required Value |
|---|---|---|
| 1 | Izod notched impact strength | 0.3 ft-lbs/in. min |
| 2 | Refractive index | 1.49 ± 0.01 |
| 3 | Water absorption, 24 hours | 0.25% max |
| 4 | Compressive deformation, 4000 psi, 122°F | 1.0% max |
| 6 | Tensile, ultimate strength<br>elongation at break<br>modulus | 9,000 psi min<br>2% min<br>400,000 psi min |
| 8 | Compressive, yield strength<br>modulus | 15,000 psi min<br>400,000 psi min |
| 9 | Shear, ultimate strength | 8,000 psi min |
| 10 | Rockwell hardness | M scale 90 min |
| 11 | Flexural, ultimate strength | 14,000 psi min |
| 12 | Specific gravity | 1.19 ± 0.01 |
| 14 | Residual monomer, methyl methacrylate<br>ethyl acrylate | 1.5% max<br>0.005% |
| 15 | Ultraviolet (290-330 nm) light transmittance | 5% max |
| 16 | Clarity, visually rated | Must pass readability |
| 17 | Coefficient of linear thermal expansion<br>at -40°F<br>-20°F<br>- 0°F<br>+20°F<br>+40°F<br>+60°F<br>+80°F<br>+100°F | (in $10^{-5}$/°F)<br>2.8 max<br>3.0<br>3.2<br>3.5<br>3.7<br>4.0<br>4.3<br>4.7 |
| 18 | Craze resistance (Type 3 only) | No crazing |

Table 3. Qualification tests for Specific Thicknesses.

| Test No. | Property | Values Required for Thicknesses of | | | | |
|---|---|---|---|---|---|---|
| | | 1/2 in. | >1/2 in. ≤1 in. | >1 in. ≤2 in. | >2 in. ≤4.250 in. | >4.250 in. |
| 5 | Displacement factor | 50 max | 80 max | 125 max | NR | NR |
| 7 | Deflection temp 264 psi | 85°C min | 88°C min | 93°C min | 93°C min | 93°C min |
| 13 | Light transmittance | 89% min | 87% min | 87% min | 85% min | NR |
| 13 | Haze | 3% max | NR | NR | NR | NR |

Note: NR means not required.

5.1.2 Test Methods and Sampling for Qualification Tests. ASTM test methods are preferred and should be used where applicable. If feasible, samples shall be cut from the 18 in. X 18 in. blank used for the optical uniformity of distortion tests (5.1.2.5) after those tests have been completed. Samples are to be cut so that no surface is closer to an unfinished cast surface than the normal trim cut. Test samples shall be cut from the central portion of the original casting of a large casting cut to yield several smaller nominal size castings. Area sampled must yield some strips about 10 in. in length (flexural and tensile tests).

5.1.2.1 Izod notched impact strength. Use ASTM D-256 Method A and report average of five test specimens. Specimens are to be cut in one arbitrarily chosen direction.

5.1.2.2 Refractive index. Use ASTM D-542 Refractometric Method and test one specimen the exposed surface of which has been given the necessary polish without gross removal of material (if possible).

5.1.2.3 Water absorption. Use ASTM D-570 Procedure 6.1 (24 hours immersion) and average three test specimens cut so that the length is in one arbitrarily chosen direction. For castings greater than 1/2 in. nominal thickness machine specimens to 3 in. X 1 in. X 1/2 in. size.

5.1.2.4 Compressive deformation. Use ASTM D-621 Method A and report average of five test specimens loaded to 4,000 psi (based on original cross section) and test at 122°F. The sample size is a 1/2 in. cube. Test nominal 1/2 in. thick material so that the as-cast surfaces serve as the load-bearing surfaces and do *not* stack samples to reach 1/2 in. height, instead test a sample 1/2 in. X 1/2 in. X nominal thickness. Nominal thicknesses over 1/2 in. should yield standard test specimens. These sampling procedures override those called out in D-621.

5.1.2.5 Optical uniformity and distortion. Determine the displacement factor per ASTM D-637 on one test specimen of 18 in. X 18 in. X thickness cut with the edges at least 3 in. from the original edge of the casting. The entire casting can be used instead of the 18 in. X 18 in. coupon, provided displacement factors are measured no closer to the edge than 3 in.

5.1.2.6 Tensile properties. Five specimens shall be tested and averaged per ASTM D-638, using testing speed "B." If feasible, specimens shall have an as-cast surface (if it is smooth enough) as one of the faces. Specimens are to be cut in one arbitrary direction.

5.1.2.7 Heat resistance. Determine the average deflection temperature under flexural load per ASTM D-648 of three specimens loaded to an outer fiber stress of 264 psi. If feasible, specimens shall be prepared so that they are loaded parallel to the original surface (if it is smooth enough). Specimens are to be cut in one arbitrary direction.

5.1.2.8 Compressive properties. Use ASTM D-695 and report average of five test specimens cut with the long axis in one arbitrary direction. The specimen shall be one solid piece whose dimensions are 1 in. X 1/2 in. X thickness of casting. When the thickness exceeds 1/2 in. samples are to be 1 in. X 1/2 in. X 1/2 in. in dimension.

5.1.2.9 Shear strength. Use ASTM D-732 and test and average five specimens cut in one arbitrary direction. When the thickness of the casting exceeds 1/2 in., machine specimen down to 1/2 in. thickness.

5.1.2.10 Rockwell hardness. Use ASTM D-785 Procedure A and make five determinations on a single 1 in. X 1 in. X thickness of casting specimen. Report average. Only a smooth, as-cast surface or equivalent shall be suitable for testing. If necessary the thickness may be reduced only as much as is needed to fit the test instrument.

5.1.2.11 Flexural properties. Use ASTM D-790 Method 1 and Procedure A with a 16/1 span-to-depth ratio. Average results of five test specimens cut in one arbitrary direction. If the thickness of the casting exceeds 1/2 in., machine specimens to 1/2 in. X 1/2 in. X 10 in. leaving one as-cast surface intact if feasible. Whenever a smooth as-cast surface exists, it should be tested in tension.

5.1.2.12 Specific gravity. Use ASTM D-792 Method A-1 and report average of three test specimens.

5.1.2.13 Light transmission and haze. Test per ASTM D-1003 Method A using illuminant C on one specimen. If the available test equipment will not handle the larger thickness, a calibrated photoelectric device can be substituted.

5.1.2.14 Residual monomer or degree of polymerization. A sample of suitable size shall be obtained and analyzed for unpolymerized methyl methacrylate and unpolymerized ethyl acrylate monomers by the techniques described in 2.1.3 or test methods producing equivalent results. Some acrylic plastics do not dissolve in solvents. The residual monomers of

these are measured in the material that is extractable from the plastic swollen in an appropriate chemical; e.g., a solid piece of Type 3 acrylic material, weighing 1 gram, is placed in 20 ml of methylene chloride in a glass bottle and placed on a shaker for 24 hours. The fluid portion of this is analyzed for monomeric methyl methacrylate and monomeric ethyl acrylate using the techniques mentioned above.

5.1.2.15 Presence of ultraviolet light absorber. Using a monochromator having a bandwidth of 10-nanometer (nm) or less, a photometer having reproducibility of ±1 percent of full scale and the practices of ASTM E-308 measure the spectral transmittance in the 290- to 330-nm wavelength band. Report value of one specimen of nominal 1/2 in. thickness or adjust value to 1/2 in. thickness. Measurements can be made on the casting or on the monomer mix from which the plastic is to be cast. Solid samples shall have two polished faces through which the light passes.

5.1.2.16 Clarity, visually rated. Visually rate the clarity of one casting by ASTM D-702-68, Paragraph 6.1.15. Clear print of size 7 lines per column inch and 16 characteristics to the linear inch shall be clearly visible when viewed from a distance of 20 in. through the thickness of the casting with opposite faces polished.

5.1.2.17 Thermal expansion. Use equipment as described in ASTM D-696 or equivalent. Test and average results of two specimens at least 5 in. long and a maximum of 1/8 in. thickness. Equilibrate the samples at −50°F and transfer to and equilibrate in constant temperatures baths controlled at −30°F, −10°F, 10°F, 30°F, 50°F, 70°F, 90°F and 110°F. A well-stirred liquid bath rising at a temperature of 2°F/min or a forced-air chamber rising at 1°F/min can be substituted for the constant-temperature baths. Measure and report the values of the coefficient of linear thermal expansion at temperatures of −40°, −20°, 0°, 20°, 40°, 60°, 80° and 100°F.

5.1.2.18 Craze resistance. Measure the craze resistance of Type 3 material only by the test method referenced in 2.1.2. Disregarding edge crazing the material shall show no evidence of crazing, cracking, or other chemical degradation in the area subjected to the action of the specified lacquer thinner only. Only a smooth as-cast surface is suitable for testing. Specimens shall be nominal 1/2 in. thick or machined to 1/2 in. thickness on the compression stressed surface only.

## 5.2 LOT ACCEPTANCE TESTING REQUIREMENTS

5.2.1 Tests and Values Required. Refer to Tables 2 and 3. Lot acceptance tests are Tests 4, 6, 8, 14, 15 and 16 and the values required are the same as those on qualification tests. The procurer has the option to require Tests 5, 13 and 16 as supplemental lot acceptance tests but must be willing to sacrifice the additional cost of these tests and the loss of the test specimens from his normal sheet or casting size.

5.2.2 Test Methods and Sampling. Use the same test methods and sampling techniques as when these tests are used as qualification tests.

## 5.3 INSPECTION OF EACH SHEET OR CASTING

5.3.1 Visual Inspection Requirements. Each sheet or casting supplied to this specification shall be visually examined and shall be:

1. completely colorless
2. free of internal cracks, checks, or crazing
3. free of defects except as modified below

5.3.2 Allowable Defects

5.3.2.1 Letgoes. Letgoes shall be permitted within an isosceles triangular area 6 in. on a side in any or all of the four corners of the sheet. The apex of the triangle must be formed by the junction of the untrimmed sheet edges. *Corner letgoes* contained in an isosceles triangle greater than 6 in. on a side but less than 12 in. on a side may be reworked and resubmitted for inspection. *Side letgoes* shall be permitted within a band not greater than 2 in. from the untrimmed sheet edge. Sheets greater than 2 in. nominal thickness may have letgoes provided they do not extend more than 1/64 in. below the surface.

5.3.2.2 Chips. Maximum allowable size shall be 1/8 in. Chips approximately 1/8 in. in size shall not have a frequency greater than one chip per 4 sq ft of surface area. Chips obviously less than 1/8 in. will be permitted unless they form a concentrated pattern that would be considered objectionable. Sheets greater than 2 in. nominal thickness may have chips provided they do not extend more than 1/16 in. above the surface.

5.3.2.3 Inclusions. Maximum allowable dimension shall be 1/16 in. Inclusions less than 1/32 in. shall be disregarded. The maximum permissible frequency for dimensions ranging from 1/32 in. to 1/16 in. shall be 1 per 4 sq ft for thicknesses up to and including 0.500 in.

5.3.2.4 Minor Defects. Minor defects which can be removed by polishing shall be permitted.

5.3.2.5 Other Defects. Other defects within 1 in. of the untrimmed edge of the sheet which do not significantly reduce the mechanical strength of the sheet shall be permitted.

5.3.2.6 Flatness of Sheets. Each sheet shall be free from edge kink warpage and from edge "S" warp. Overall bow warp of 3/8 in. or less when the casting is placed concave side down on a flat surface shall be permitted.

## SECTION 6

## PREPARATION FOR DELIVERY

### 6.1 PROTECTION

6.1.1 **Masking.** The viewing surfaces of each casting shall be covered by a suitably adhered paper, tape or film that can be readily removed without injury to the surfaces and that will adequately protect the surfaces from scratching or damage during handling, shipping, or storage. When removed from the surface, the masking material shall leave no residue.

### 6.2 MARKING

6.2.1 **Traceability.** A material identification and accounting system shall be used so that at any time (up to and including delivery) it is possible to trace any piece of material, test samples or test results to the particular casting from which they were cut or to which they apply.

6.2.2 **Individual Castings.** The protective covering of each casting shall be legible and permanently marked with the following minimum information.

- a. The specification number.
- b. The supplier's designation for his approved product.
- c. The nominal thickness.
- d. Markings consistent with 6.2.1.

Markings shall appear at least once on each casting and preferably at intervals of one ft.

6.2.3 **Shipping Containers.** Each package and container shall be marked permanently and legibly with the following minimum information.

- a. Material description.
- b. Specification number.
- c. Purchase order number.
- d. Manufacturer, code number, batch number, and lot number.
- e. Date of manufacture.
- f. Results of Lot Acceptance Tests.
- g. Markings consistent with 6.2.1.

## FORM 1

## QUALIFICATION TESTS RESULTS

| | |
|---|---|
| Trade name | Grade |
| Manufacturer | Nominal Thickness |
| Identification | Type |

Thickness category

| Test No. | Property | Test Method & Sampling Ref. | Results Reported to | Test Results |
|---|---|---|---|---|
| 1 | Izod impact | 5.1.2.1 | 0.1 ft-lb/in. | |
| 2 | Refractive index | 5.1.2.2 | 0.01 | |
| 3 | Water absorption | 5.1.2.3 | 0.01% | |
| 4 | Compressive deformation | 5.1.2.4 | 0.1% | |
| 5 | Displacement factor | 5.1.2.5 | 1 | |
| 6 | Tensile, strength | 5.1.2.6 | 100 psi | |
| | elongation | | 0.1% | |
| | modulus | | 10,000 psi | |
| 7 | Deflection temperature | 5.1.2.7 | 1°C | |
| 8 | Compressive, strength | 5.1.2.8 | 1,000 psi | |
| | modulus | | 10,000 psi | |
| 9 | Shear strength | 5.1.2.9 | 1,000 psi | |
| 10 | Rockwell hardness | 5.1.2.10 | 1 | |
| 11 | Flexural strength | 5.1.2.11 | 1,000 psi | |
| 12 | Specific gravity | 5.1.2.12 | 0.01 | |
| 13 | Light transmittance | 5.1.2.13 | 1% | |
| 14 | Residual methyl methacrylate | 5.1.2.14 | 0.1% | |
| | Residual ethyl acrylate | | 0.001% | |
| 15 | Ultraviolet transmittance | 5.1.2.15 | 0.5% | |
| 16 | Visual clarity | 5.1.2.17 | pass or fail | |
| 17 | Thermal expansion at: | 5.1.2.18 | $0.01 \times 10^{-5}$/°F | |
| | -40°F | | | |
| | -20°F | | | |
| | 0°F | | | |
| | +20°F | | | |
| | +40°F | | | |

FORM 2

## LOT ACCEPTANCE TEST RESULTS

| | |
|---|---|
| ______________________ Trade name | ______________________ Grade |
| ______________________ Manufacturer | ______________________ Nominal thickness |
| ______________________ Identification | ______________________ Type |

Specification Reference

| Test No. | Test Method & Sampling Ref. | Property | Results Report to | Test Results |
|---|---|---|---|---|
| 4 | 5.1.2.4 | Compressive deformation | 0.1% | |
| 5* | 5.1.2.5 | Displacement factor | 1 | * |
| 6 | 5.1.2.6 | Tensile, strength | 100 psi | |
| | | elongation | 0.1% | |
| | | modulus | 10,000 psi | |
| 8 | 5.1.2.8 | Compressive, strength | 1,000 psi | |
| | | modulus | 10,000 psi | |
| 13* | 5.1.2.13 | Light transmittance | 1% | * |
| 14 | 5.1.2.14 | Residual methyl methacrylate | 0.1% | |
| | | Residual ethyl acrylate | 0.001% | |
| 15 | 5.1.2.15 | Ultraviolet transmittance | 1% | |
| 16 | 5.1.2.17 | Visual clarity | pass or fail | |
| | 5.3 | Inspection | pass or fail | |

*These tests are supplemental lot acceptance tests and will *not* normally be run unless specifically requested (see 5.2.1).

NOTES: 1. Requirements are given in Tables 2 and 3 in 5.1.1.
2. Only materials listed on the QPL are considered eligible.
3. Each casting is to be tested.

Date ______________________

I, ________________ of ______________ County, State of __________, being duly sworn, depose and say that the above identified material was tested in the prescribed manner and that the test results are true and accurate.

Name ______________________

Title ______________________

Company ______________________

Subscribed and sworn to before me on this __________ day of __________, AD ______________ and hereby affix my seal.

Name ______________________________
Notary Public

## APPENDIX B
## BIBLIOGRAPHY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